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THE ECONOMIC VALUE OF REMOTE
SENSING OF EARTH RESOURCES FROM SPACE:
AN ERTS OVERVIEW AND THE VALUE OF
CONTINUITY OF SERVICE

VOLUME I

SUMMARY

Prepared by

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and

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for the
Office of the Administrator
National Aeronautics and Space Administration
Under Contract NASW-2580

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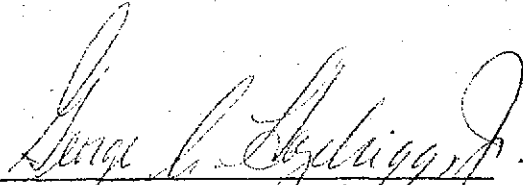
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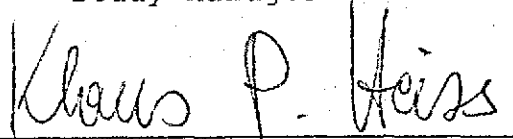
NOTE OF TRANSMITTAL

This summary report is prepared for the Office of the Administrator, National Aeronautics and Space Administration, under Article I.C.1 of Contract NASW-2580. It represents a condensation of material from the Source Document, Volume II, and the Source Document backup Volumes III to X of this report. The interested reader is referred to these documents for substantiation of all data presented herein.

The data presented in this summary and in the source document are based upon the best information available at the time of preparation. This includes a survey of existing studies. Four case studies, two in agriculture and one each in water use and land use are discussed in this summary. Others are discussed in the Source Document and supporting volumes. Throughout the analysis, a conservative viewpoint on the potential of ERS has been maintained. Nonetheless, there are, of course, uncertainties associated with any projection of future economic benefits, and these data should be used only with this understanding.



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ABSTRACT

The Earth Resources Technology Satellite (ERTS) Program faces some crucial decisions over the next 12 to 18 months that will affect the future of remote sensing by satellite for decades to come. The purpose of this report is to provide an overview of the ERTS program to date, to determine the magnitude of the benefits that can be reasonably expected to flow from an Earth Resources Survey (ERS) Program, and to assess the benefits foregone in the event of a one-year or a two-year gap in ERS services occurring in 1977-1978.

A very substantial body of information in the form of other economic and technical studies concerning ERS benefits exists. As far as that information relates to this economic assessment, it is herein collected, evaluated and included. However, the heart of this effort is an independent evaluation of the benefits attributable to ERS-derived information in key application areas. These include two case studies in agriculture - distribution, production and import/export - and one study in water management. In addition, a land cover case study addresses the issue of the cost-effectiveness of satellites in an ERS system.

The annual benefits achievable from an ERS system, assuming continuity of service, year-by-year, by say 1985, are measured by the in-depth case studies to be in the range of \$430 million to \$746 million. Significant additional potential benefits are qualitatively discussed. The present value of benefits foregone in the event of a one-year gap in ERS service occurring in 1977 is estimated to be \$220 million evaluated at a 10% discount rate and \$147 million at a 15% discount rate. The present value of benefits foregone in the event of a two-year gap, 1977-1978, are \$420 million and \$274 million respectively for a 10% and 15% discount rate.

All benefit and cost figures in this report are in 1973 dollars.

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STUDY ORGANIZATION

Purpose

The purpose of this study is to provide an overview of the economic benefits to the United States of a space-based Earth Resources Survey (ERS) Program and to determine the value of assured continuity of data gathering activities on a level at least equal to that provided by the ERTS-1 satellite. The results are summarized here, Volume I. The Source Document, Volume II, provides a "first-order" documentation of this volume. Volumes III to X provide further documentation, area-by-area, of Volume II.

Components of Economic Assessment

The economic benefits in crucial areas were estimated independently by ECON*, and a full documentation of these estimates is given in the Source Document and the appended volumes for each application area. A very substantial body of information in the form of other economic and technical studies concerning ERS benefits exists. As far as that information relates to this economic assessment, it is herein collected, evaluated and included.

The flow and organization of the study is shown in Figure i. Studies concerning benefits and costs of an ERS system have been performed over a number of years (since at least 1959). Most deal with some individual aspect of the economic assessment of an ERS system. In this study, this vast amount of information is organized into a comprehensive overview and evaluated case-by-case. This assessment deals with the benefits of an ERS system with capabilities similar to ERTS plus a thermal IR channel, not its costs; nor is an attempt made to optimize economically the ERS system. The benefits, documented in past and present studies, are organized into three groups:

1. *Equal capability benefits:* cost savings, accruing to ongoing operations or projected operations in

* Distribution, Production and Import/Export Effects in U.S. Agriculture with Information for the United States, Land Cover Cost-Effectiveness of ERTS, Water Resources Application ad hoc case study.

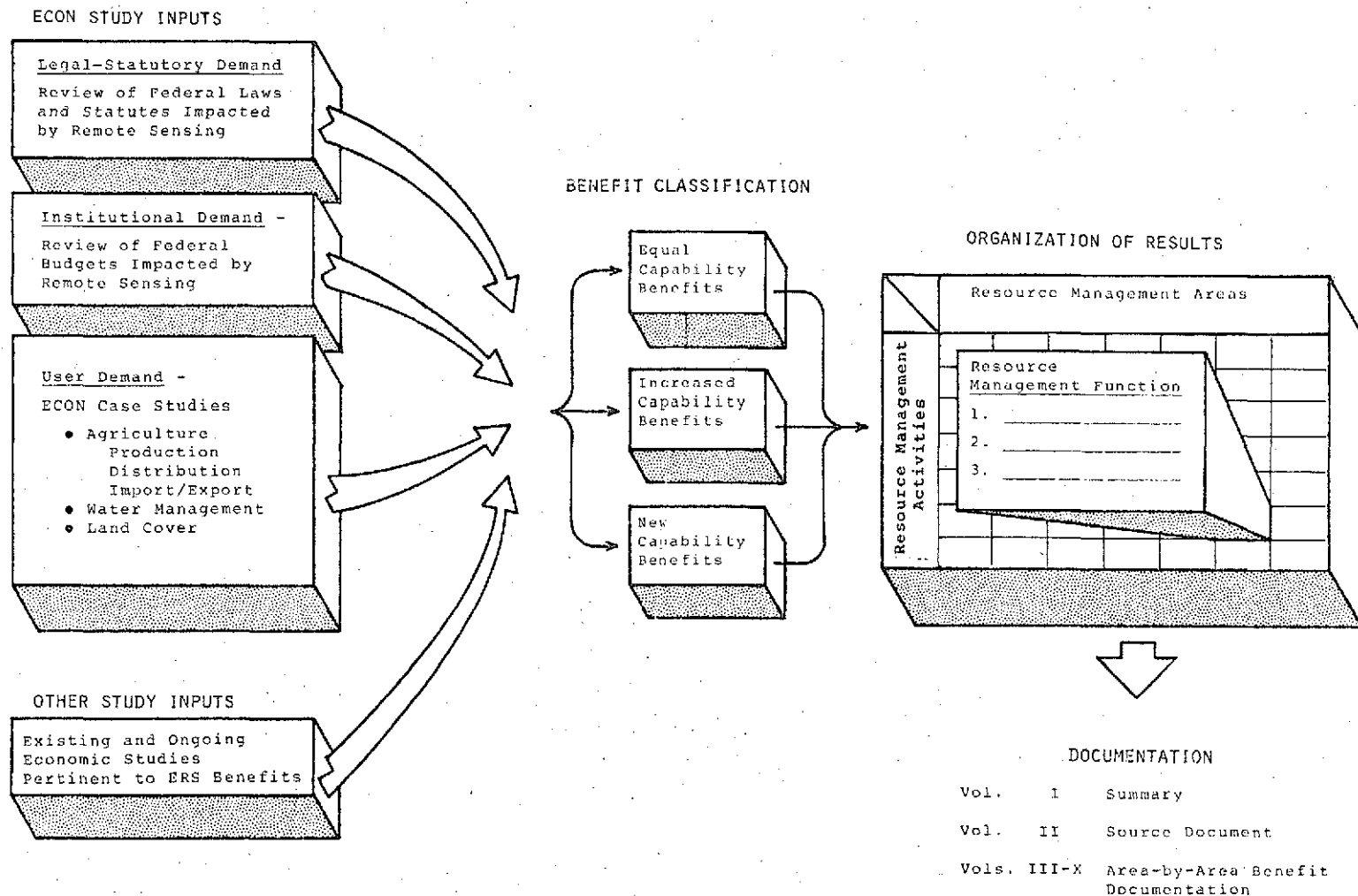


Figure i Study Organization

gathering information, in most cases in conjunction with other ongoing activities (aircraft, ground investigations).

2. *Increased capability benefits:* the value of increased capabilities to meet federal, state, and local government as well as private data gathering needs above and beyond presently ongoing activities.
3. *New capability benefits:* due to the unique capabilities offered by a space-based ERS system providing worldwide coverage and aggregate, timely coverage of the United States. These benefits are presently achievable, within budget and activity constraints by either industry or government, however, *only by use of a space-based ERS system.*

In the context of the above categories of benefits, resource management areas covering the span of Earth resources are defined:

1. Intensive use of living resources: agriculture
2. Extensive use of living resources: forestry, wildlife and rangeland
3. Inland water resources
4. Land use
5. Nonreplenishable natural resources: minerals, fossil fuels and geothermal energy sources
6. Atmosphere
7. Oceans
8. Industry

Each of these resource management areas are further classified into nine use-oriented resource management activities. These are:

1. Cartography, thematic maps and visual displays
2. Statistical services

3. Calendars
4. Allocation
5. Conservation
6. Damage prevention and assessment
7. Unique event recognition and early warning
8. Research
9. Administrative, judicial, and legislative

Within the resulting matrix of resource management areas and resource management activities, specific resource management functions (RMF's) are identified as they occur in agriculture, water management, rangeland and forestry management, etc. The RMF's pertain to specific management functions that might benefit from some form of ERS information.

The above classification scheme is used to organize the existing information on ERS systems with an emphasis on quantitative benefit estimation.

The Demand for ERS Information

To document the possible demand for remote sensing within each application area, three broad sources of demand for ERS information are distinguished. These are:

1. *Legal and Statutory demand:* This includes laws and statutes at the federal, state, and local level which would be satisfied by, or require remotely sensed data. For each application area an ad hoc review of pertinent laws and statutes is documented in Volumes III through X.
2. *Institutional demand:* The institutional demand consists of budgetary allocations for data gathering activities that could be impacted by an ERS system. A review of the present budgetary allocations at the federal level and, rather incompletely, at the state and local level for activities and functions which could use remote-sensed information are given for each of the application areas, also in Volumes III through X.

3. *User demand:* This demand is created by ERS activities that result in benefits independent of existing laws, statutes and budgets. The user demand is the major source of ERS benefits and its estimation in agriculture and water resources is the subject of the case studies outlined in Chapter 3 of this volume and supported by the further analyses presented in Volumes III to X.

The statutory and legal demand, as well as the institutional demand, for ERS information leads to benefits for this information; however, statutes and laws as well as budgetary allocations by themselves are only the starting point and framework within which the actual benefit estimation by resource management area, and possibly by resource management function, has to occur.

The Case Studies Effort

The heart of this study is an evaluation of the demand for ERS data due to the user demand. To do an independent economic evaluation of the key areas of user demand, ECON performed *specific case studies in agriculture areas* (distribution effects, production effects and import-export effects of remotely sensed information on the United States only, for United States use), in *water management* and, finally, a comprehensive cost-effectiveness analysis of ERS assistance to provide United States *land cover information* (space-based, high altitude aircraft, aircraft and ground systems).

The agricultural case study efforts covering many areas of investigation are presented fully in Volume III. These case study efforts were funded under separate contract (NASW 2558) parallel to this overview effort. They are included here to document the basis of benefit estimation in the overview effort. The agricultural case studies are the cornerstone of the economic evaluation. In each of the case studies the purpose was to measure, in a credible way, the economic benefits of *providing added information* in the agriculture sector concerning distribution, production, and import-export decisions. The evaluation concentrated on an analysis of wheat and small grains, but, where feasible, was extended to include other crops, particularly soybeans.

The methodology in each of the in-depth case studies in agriculture is described in the Source Document, Volume II, as well as Volume III, documenting the agricultural evaluation effort. In each of these efforts the economic analysis goes substantially beyond anything existing today for purposes of evaluating added information and its impact in the agriculture sector of the U.S. economy. The economic methodology, and the results of this effort, are open for review and discussion with any appropriately constituted economic review panel.

Certainly not all aspects, and problem areas, as well as opportunities for remotely sensed information are considered here. However, the case studies as performed provide *strong support for the economic evaluation and results as presented in this study.* The potential of ERS information used in the agriculture sector alone is substantial. Given the rigor of the economic approach, and the comprehensiveness of the agricultural case studies in particular, the results presented here provide a firm economic foundation.

The *technical* performance evaluation of an ERS system in each of the application areas was *not part of this effort*: its estimation is based on the extensive information now available on ERTS-1 principal investigator results, the efforts carried on in the Department of Interior study, the many symposia and reviews of technical findings and, in the agricultural area, the report by the Task Force on Agricultural Forecasting of the Goddard Space Flight Center.*

* Wood, D.B., et al., "The Use of the Earth Resources Technology Satellite (ERTS) for Crop Production Forecasts", Task Force on Agricultural Forecasting, Goddard Space Flight Center, Draft Final Report, July 24, 1974.

1. STUDY OVERVIEW

The NASA Earth Resources Survey Program (ERSP) faces some crucial decisions over the next twelve to eighteen months that will shape not only the future of the Earth Resources Technology Satellite (ERTS) Program, but also set the course for remote sensing Earth-resources programs for many years to follow.

In the years ahead, resources issues will become of increasing social and economic importance. For example, there is now strong evidence that profound secular global changes are occurring: changes in climate, changes in resources availability and prices, and changes in world trade relations. Man will face the danger of recurring widespread famine, depletion of certain mineral and other natural resources, and permanent changes in the ecology.

National leaders and resource managers will do their best to avert problems. But there exists a lack of scientific understanding regarding the basic interactions of our natural resources and a lack of information on the current state of these resources. Hard evidence on what is happening worldwide, in real time, can lend substantial support to the process of better resource management, national and worldwide.

In this study, the emphasis is on estimating quantitatively the effects and interactions of added (remote sensed) information on the United States for use in the United States. However, in the case of many information applications information obtained on areas outside the territories of the United States is of value to the United States. These applications are also studied and reported herein, albeit tentatively. Not included in the scope of this study are the benefits that may accrue to other nations and regions of the world.

1.1 Groundrules and Objectives

As a first step toward a worldwide Earth Resources Survey (ERS) satellite system, on July 23, 1972, NASA launched the ERTS-1 satellite. In addition to the ERTS-1 satellite and as part of the ERTS Program, a second satellite, ERTS-B was procured. In this study, it is assumed that the ERTS-B satellite will be launched in February 1975 and will remain in a fully operational mode for two years. It is also assumed that, through this period and beyond, the Federal government will own and operate an ERS satellite system - satellites and national ground stations - and provide a data distribution

mechanism that affords timely, non-discriminatory access to all data acquired. It is further assumed that satellites beyond ERTS-B will have a thermal IR channel.

After the useful lifetime of the ERTS-B satellite, the course of remote-sensing Earth-resources by satellite becomes uncertain. There exist ongoing programs for other ERS satellites but none of these will be ready to fill the role of ERTS immediately after ERTS-B.* Thus, two primary options are now available:

- (1) to allow a gap to occur after ERTS-B (1977, 1978) or,
- (2) to assure continuity of ERTS-type coverage after the expected lifetime of ERTS-B.

The purpose of this report is twofold. First, to review the economic value to the United States of an ERS Program and, second, to determine the economic value of continuity of coverage in obtaining ERS benefits.

A review of the economic benefits to the United States (under the above groundrules) of an ERS Program with capabilities similar to ERTS must face two issues:

- (1) What are the "real" or economically measurable benefits that can be reasonably expected to flow, year-by-year, from an ERS system?
- (2) What is the likely distribution of the measurable benefits to be expected from an ERS system?

The economic value of continuity of coverage derives from addressing a third question:

- (3) What are the economic benefits foregone in the event of a one-year gap and a two-year gap in ERS coverage providing at least the capabilities of an ERTS system?

Finally, a fourth question is addressed in a qualitative approach in Chapter 5 of this summary:

- (4) What are the indirect or difficult-to-quantify benefits that are derived from an ERS Program?

* The benefits of any such (eventual) future system are not included in this evaluation.

The benefits addressed under the last question include the use of an ERS system as a research tool, the short-term versus long-term aspects of economic benefit estimation, acknowledgment of certain social values obtained, for example, in ecology, and the value of an ERS Program as part of an overall foreign aid program.

1.2 The Value of Remote Sensing

The answers to the first three questions above are obtained by analyzing first the benefits achievable from an ERS system, assuming continuity of coverage, year-by-year, say by 1985. This effort comprises mainly a review of existing literature on previous economic studies of remote sensing of Earth resources from space and includes additional information generated by a limited number of case studies performed by ECON in support of this study. These data form the basis from which the answers to the above questions are derived.

All Earth resources activities have been grouped into eight categories. These categories and the major ERS activities performed in each are:

1. *Intensive Use of Living Resources: Agriculture* - This area encompasses products of all intensively cultivated lands exclusive of forest and range-land products. ERS activities of benefit consist primarily of surveying and inventoring crop acreage by crop type in order to provide data for better crop yield information on a national basis and in the control of crop stress and disease. Combined with this is the long range potential of establishing real-time regional and worldwide agricultural calendars.
2. *Extensive Use of Living Resources: Forestry, Wildlife and Rangeland* - This area includes all living land resources not contained in the first category. ERS activities of benefit consist primarily of monitoring forest, rangeland, and wilderness conditions in order to provide information for better long-term utilization and control of these areas, fire prevention and control, and disease prevention and control. Many of these areas are very remote and can be economically best observed from space.

3. *Inland Water Resources* - This includes all management functions dealing with inland water, exclusive of estuaries. ERS data can provide a measure of snow cover and ground wetness in mountainous watershed areas which can lead to improved management of water impoundment areas and flood control systems. The resulting management improvements can provide an increased water supply for hydropower generation, irrigation, residential and industrial uses and can reduce the probability of damage due to flooding.
4. *Land Use* - Current requirements for regulation of developing lands--urban growth, loss of agricultural land to residential and industrial purposes, zoning and planning, cartography--create a substantial demand for remote sensing. ERS satellite data can be substituted for aircraft data with substantial cost savings and provide at the same time an increased coverage capability. In the context of this study, land use refers to a legal and statutory demand for total area coverage as opposed to sampling for specific data requirements.
5. *Nonreplenishable Natural Resources: Minerals, Fossil Fuels, and Geothermal Energy Sources* - This area includes the exploration for and use of all nonreplenishable natural resources. Although the exploration for and use of these resources is conducted in a highly intensive manner, ERS satellites provide a new vantage point from which a synoptic view can be obtained. This new look at the earth can provide improved understanding of the location, distribution and extent of these resources and the impact of their extraction and use.
6. *Atmosphere* - Increased worldwide industrialization and use of fossil fuels makes evident the fact that Earth's atmosphere is a limited resource. Proper management of this resource requires regulation of damaging emissions. ERS space data may be supportive of other space systems and ground systems: ERS satellite data provide a means of monitoring pollution sources and dispersion and also provide a first source of synoptic imagery useful for micro-scale meteorological studies.

7. *Oceans* - This resource includes all ocean products and estuarine management. ERS data can provide a better understanding of ocean currents, tides and fresh water plumes. The thermal mapping of the Northern Pacific, yearly or monthly, may provide more accurate "initial state" conditions for use in climatic and weather predictions. With the advent of dedicated ocean satellite systems, for example, SEASAT, this benefit would be attributed to those systems. Proper understanding of these phenomena is necessary for continued use of the oceans for waste disposal and improved seafood harvest.
8. *Industry* - This area covers the entire capital plant, including industrial and residential buildings, manufacturing equipment, transportation facilities, and other infrastructure. ERS satellite data can provide information for improved location and management of these facilities and capabilities.

Three categories of benefits have been identified in each of the eight resource management areas. These include cost saving for doing things which are currently done (equal capability), benefits attributed to doing more of the same activities as are currently being done (increased capability), and benefits from doing entirely new activities made possible by the ERS satellite system (new capability). Potential annual economic benefits, assuming continuity of service, are given in Tables 1.1. It is to be emphasized that the benefits are "short-term" (1980s) in that they are based upon the demand for data, the price structures and resource availabilities today. Furthermore, the benefit estimates are limited to those applications of ERS data which are now quantifiable. Therefore these are, in all probability, conservative estimates of potential ERS benefits. The costs of an ERS satellite system are given in Table 1.2.

On the basis of the total economic value of remote sensing given in Table 1.1a the answers to the first three questions posed (p. 1-2) are as follows:

- (1) The measured benefits that can be reasonably expected to flow in the 1980s, year-by-year, from an ERS system are about \$450 million.
- (2) The distribution of the measured benefits by application area is given in Table 1.1a. The incidence of these benefits on different sectors of the U.S. economy, and people, to be expected from an ERS system is discussed in Section 3.4.

- (3) The economic benefits foregone in the event of a one-year gap in ERS coverage providing at least the capabilities of an ERTS system are \$220 million (1973) at a 10% discount rate and \$147 million (1973) at a 15% discount rate. For a two-year gap, the benefits foregone are \$420 million (1973) and \$247 million (1973) respectively.

Table 1.1a . Measured Annual Potential U.S. ERS Benefits, by, Say, 1985* (Firm Benefit Estimates Derived from In-Depth Case Studies Only)				
Resource Management Areas	Benefits by Type, \$ millions (1973)			
	Equal Capability	Increased Capability	New Capability	TOTAL
1. Intensive use of Living Resources: Agriculture	5.5	106-247	141-302	252.5-554.5
2. Extensive Use of Living Resources: Forestry, Wildlife, & Rangeland	4.0	3.7	54.5	62.2
3. Inland Water Resources	3.3	3.3	50.6	57.2
4. Land Use		53.5**		53.5**
5. Nonreplenishable Natural Resources: Minerals, Fossil Fuels, and Geothermal Energy Sources	1.6-3.9			1.6-3.9
6. Atmosphere	1.5-10.5			1.5-10.5
7. Oceans	.55	1.2-3.7		1.75-4.25
8. Industry				
TOTAL	16.3-27.7	167.6-311.1	246.1-407.1	430-746
<p>* All numbers in this table are substantiated in detail by case studies documented in Volumes III through X. Assumes assured continuity of service.</p> <p>** This number derives from legal and statutory requirements outlined in Volume VI. The benefits shown here are gross benefits, i.e., the annual program costs as shown in Table 1.2 are not deducted.</p> <p>† Substantial benefits may be possible due to remote sensing from space but have not been quantified nor, specifically, were they attributed to ERS. See Volume X for discussion.</p>				

Table 1.1b Total Projected Annual Potential U.S. ERS Benefits by, Say, 1985* (Benefit Estimates from Table 1.1a Plus Expected Benefits Not Verified by In-Depth Case Studies)				
Resource Management Area	Benefits by Type, \$ millions (1973)			
	Equal Capability	Increased Capability	New Capability	Total
1. Intensive Use of Living Resources: Agriculture	58.3	164.4-479.4	503.6-974	726.3-1511.7
2. Extensive Use of Living Resources: Forestry, Wildlife, & Rangeland	4.0	3.7	84.5	92.2
3. Inland Water Resources	29.1-65.2	27.6-62.5	50.6	107.3-178.3
4. Land Use		53.5**		53.5**
5. Nonreplenishable Natural Resources: Minerals, Fossil Fuels, and Geothermal Energy Sources	34.6-80.9			34.6-80.9
6. Atmosphere	1.5-10.6	.5-1.2	5.1-27.3	7.1-39.1
7. Oceans	5.6-13.3	1.2-3.7	††	6.8-17.0††
8. Industry	†	†	†	†
TOTAL	133.1-232.3	250.9-604.0	643.8-1136.4	1027.8-1972.7
<p>* All numbers in this table are substantiated in detail in Volumes III through X. This table includes all benefits reported in Table 1.1a plus additional benefits which are generally valid order of magnitude numbers but which are not backed up by in-depth case studies.</p> <p>** This number derives from legal and statutory requirements outlined in Volume VI. The benefits shown here are gross benefits, i.e., the annual program costs as shown in Table 1.2 are not deducted.</p> <p>† Substantial benefits may be possible due to remote sensing from space but have not been quantified nor, specifically, were they attributed to ERS. See Volume X for discussion.</p> <p>†† Benefits result from high resolution thermal monitoring of the North Pacific to the United States. They will not be captured by an ERTS-like ERS system if other satellites with greater capability are in use in this area. Therefore these benefits are not included here.</p>				

Figure 1.1 presents projected costs and anticipated benefits from an operational ERS system. Costs are for a one- and three-satellite system being launched in 1977; they represent upper limits of costs for satellites with an expected two-year lifetime. Cost figures are derived from Tables 1.5 and 1.8, Volume II. Benefits are derived from those documented in ECON case studies, where the lower bound hard benefit figures are assumed to be realized by 1985 and the upper bound figure realized by 1992. Benefits are based on an ERTS-like satellite system. The lower limit of the hard benefits could probably be achieved using a two-satellite system while the upper limit of these benefits would probably require a three-satellite system.

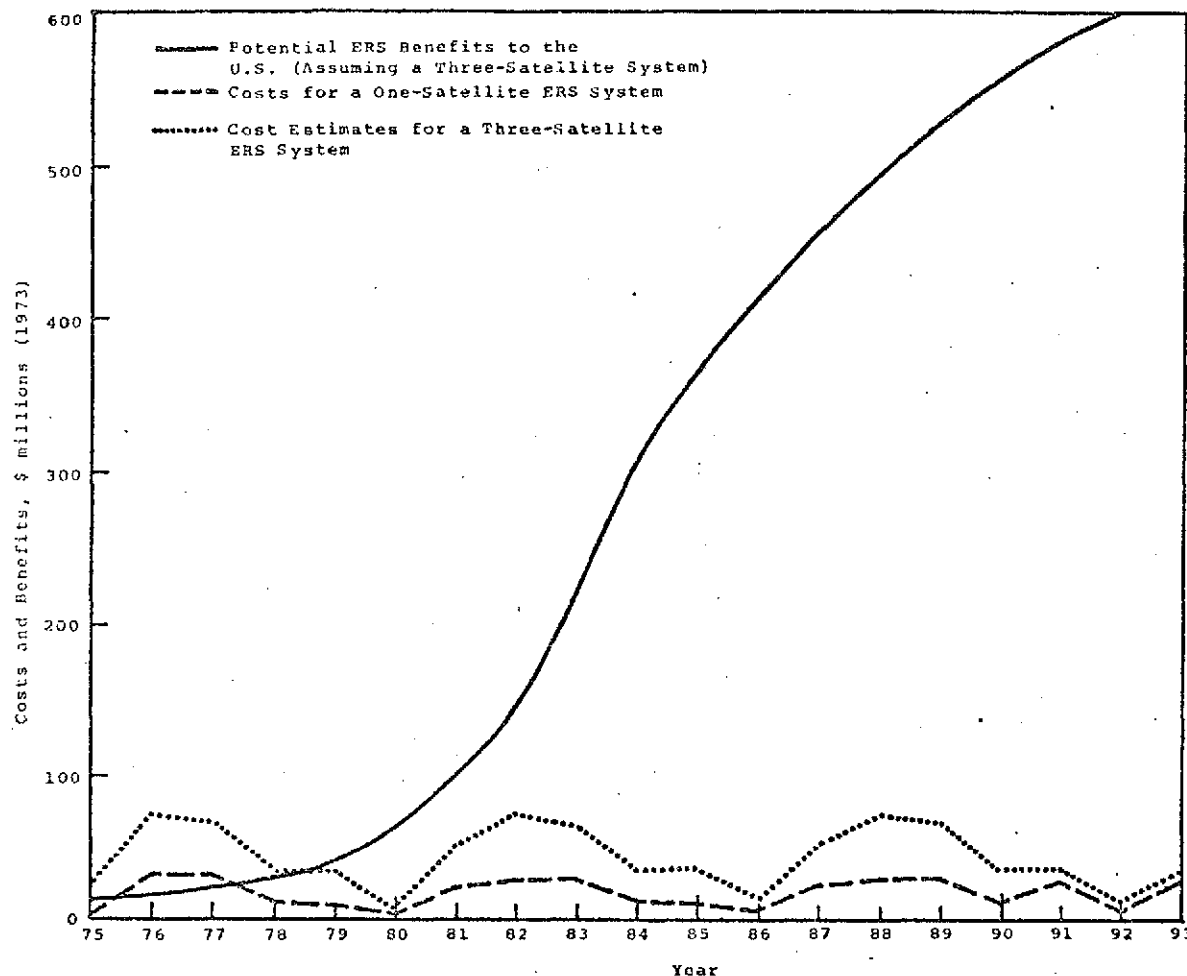


Figure 1.1 Projected Costs and Benefits for an ERS System

1.3 Highlights of the ERTS-1 Mission

In the two years that ERTS-1 has been in space, it has returned over 100,000 images of the earth, covering about 75 percent of the land mass and coastal areas, with less than 30 percent cloud cover. The return beam vidicon (RBV) and both wide band video tape recorders on ERTS-1 experienced anomalies early in the mission, thus most image data are restricted to multispectral scanner (MSS) images of areas from which a real-time downlink to a ground station is possible. Continued operation of ERTS-1 cannot be expected to significantly increase the world area imaged. However, with the launch of ERTS-B, no doubt, new areas will be imaged revealing new surprises of significance to mankind.

During the active period of ERTS-1 to date, the emphasis has been on developing a deeper scientific understanding of the capabilities of ERS satellites. Over 600 scientific groups worldwide have used ERTS-1 data. A select set of the ERTS-1 images have already had a profound impact on the management of certain resources and in obtaining a better *scientific* understanding of our environment. These certainly include but are not limited to the following:

- (1) An image of a major agricultural area in the San Joaquin Valley of California. This image, Figure 1.2, indicates the ability of ERTS to depict agricultural areas. Investigation based on this and similar images verify an ability to identify a variety of crop types.

Table 1.2 Total Program Costs For An ERS Satellite System, 1977-1993*			
Type of Cost	Costs for 1, 2 and 3 Simultaneously Active Satellites, \$ millions (1973)		
	1**	2**	3***
Investment Costs	258	494	645
Operation Costs	84	117	150
Civil Service Costs	26	40	58
Total Costs	368	621	853
Annual Cost Annuities at 10% Discount Rate	27.3	45.6	61.9
<p>* These data are based on the following assumptions:</p> <ol style="list-style-type: none"> 1. A two-year satellite lifetime 2. A sixteen and one-half year program 3. Civil Service costs are a percentage of annual total investment and operating costs. 4. Includes costs incurred up to data on tapes at ground receiving station. 5. The one-satellite case requires nine satellites operating over 16 years; the two-satellite case requires 18 satellites operating over 16 years; the three-satellite case requires 27 satellites operating over 16 years. 6. All investment costs are distributed as indicated in Vol. II, Tables 1.5, 1.7 and 1.8. <p>** See Volume VI for further documentation backup.</p> <p>*** ECON estimates based upon NASA GSFC data for a single-satellite system. Actual costs would probably be lower due to sensible system changes to more efficiently obtain the increased technical capability.</p>			

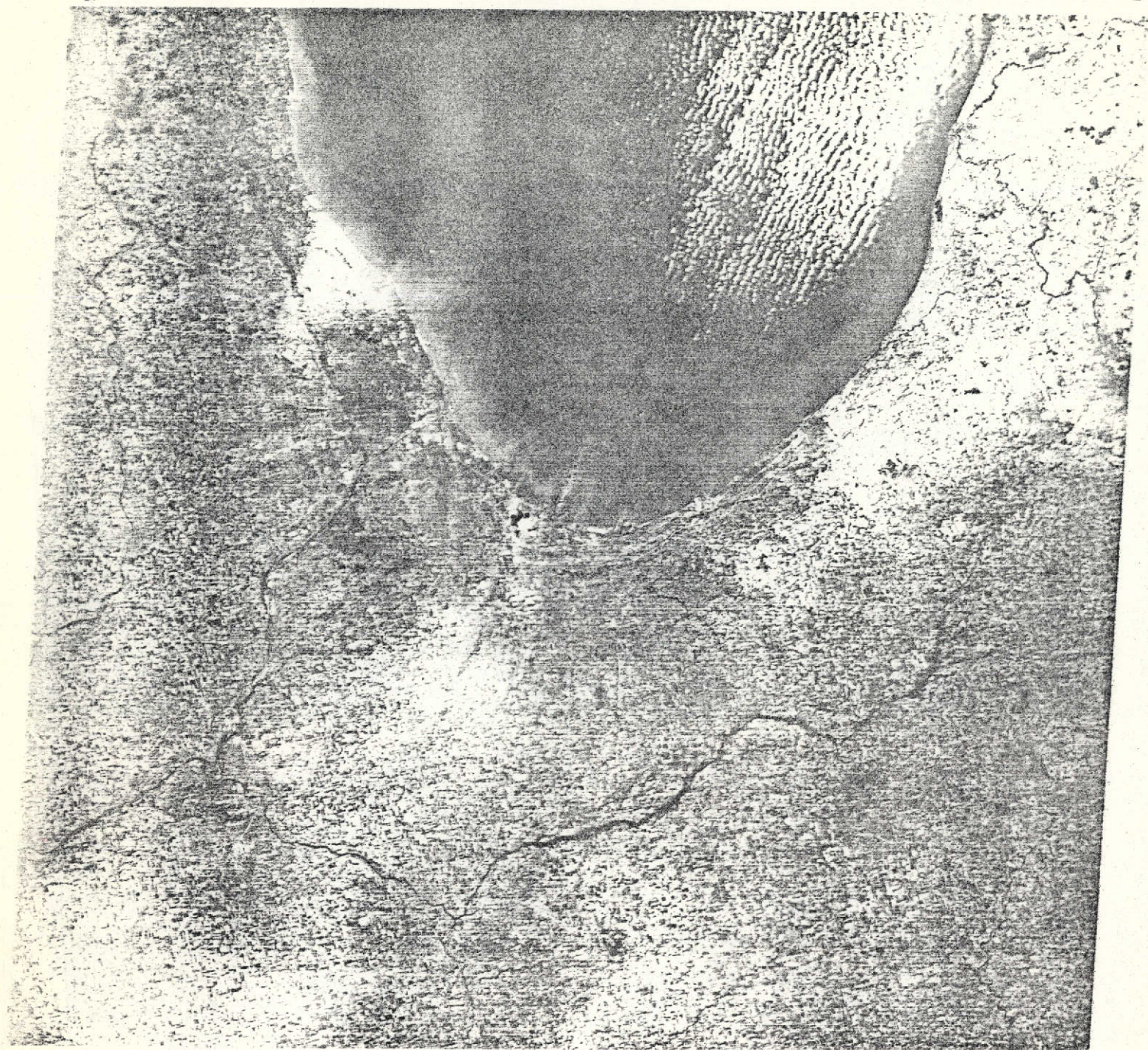
- (2) An image of lower Lake Michigan, Figure 1.3, showing clearly, and for the first time conclusively, that pollution sources on the South Shore affect weather patterns and rainfall in Michigan. (See discussion, Chapter 5 and RMFs 6.2.2 and 6.6.1, Vol. VIII.)
- (3) An image of Southern California, Figure 1.4 (a and b) showing a fully developed Santa Ana wind condition. This is the first synoptic image of this phenomenon obtained with a sufficiently fine resolution to be useful in a micro-scale weather study. (See discussion, RMF 6.2.4, Vol. VIII.)
- (4) An image of Western Africa, Figure 1.5, showing the major region of the current drought and including the discovery of a productive area of land. Combined with groundbased data, this discovery could help to provide new land management practices that will lessen the strife of that area. (See discussion, Chapter 5.)
- (5) An image of the Los Angeles Basin, Figure 1.6, printed to show land use. Note the use of colors to emphasize urban area features as opposed to agricultural areas. (Compare this to Figure 1.4b.)

These brief examples indicate singularities of high visibility and substantial impact on the management of Earth resources. Yet the major benefits of an ERS system do not lie in an occasional event of high visibility but rather in the day-to-day, mundane resource monitoring operations as outlined in Section 1.2 that take place on an image-by-image basis, extracting bits of data from individual images and image components ("pixels") and combining these into regional, national, and worldwide data banks from which information can be derived leading to better resource management decisions.



1W120-30 W120-001 W119-301 W119-001
 26MAY73 C N36-08/W119-34 N N36-07/W119-28 MSS 5 D SUN EL62 AZ115 190-4281-G-1-N-D-2L NASA ERTS E-1307-18071-5 01

Figure 1.2 ERTS-1 Image of a Major Agricultural Area of the San Joaquin Valley of California.



W088-30 W088-201
24NOV72 C N41-40/W087-24 N N41-38/W087-20 MSS

W087-301 W087-201
D SUN EL24 AZ156 191-1728-N-1-N-D-2L NASA ERTS E-1124-16050-3 01

Figure 1.3 ERTS-1 Image of Southern Lake Michigan
Showing that Pollution from Steel Mills
in Gary, Indiana, Changes the Weather in
Michigan



119-00 1119-301 318-00W 117-300
 21JAN73 C N35-59/W117-57 N N35-56/W117-52 MSS D SUN EL25 AZ150 190-2259-G-1-N-D-2L NASA EPTS E-1162-18011-5 01

Figure 1.4a ERTS-1 of the Mojave Desert Area of
 Southern California Showing a Fully
 Developed Santa Ana Wind Condition
 (Montage with Figure 1.4b.)



W119-001
01JAN73 C N34-32/W118-24 N N34-30/W118-18 MSS

W118-301
D SUN EL26 AZ150 190-2259-G-1-N-D-2L NASA ERTS E-1162-18013-1 01

W118-001

Figure 1.4b ERTS-1 of the Mojave Desert Area of Southern California Showing a Fully Developed Santa Ana Wind Condition (Montage with Figure 1.4a.)

00MAY73 C N15-58/E004-00 E003-301 N N15-55/E004-05 MSS 5 R SUN EL60 A2083 188-4025-A-1-N-D-2L NASA ERTS E-1269-09365-3 01

Figure 1.5 ERTS-1 Image of the Sahel Region of Western Africa Showing a Productive Area of Land

W119-00

W118-001

W118-001

W117-001



W119-00 W119-001 N033-001 W118-00 W118-001
 10AUG72 C N34-19/W118-27 N N34-19/W118-24 MSS 67 D SUN EL57 AZ118 190-0251- -1-N-D-2L NASA ERTS E-1018-10010-9 01

LOS ANGELES - VENTURA

10 AUG 1972

PHOTOGRAPHIC COPY OF
 DYE TRANSFER COLOR COMPOSITE MADE BY HUGHES
 FROM ERTS-MSS BLACK AND WHITE
 POSITIVE 949 mm TRANSPARENCIES SUPPLIED BY NASA
 DYE COLOR ASSIGNMENTS
 BAND 5 - YELLOW
 BAND 6 - MAGENTA
 BAND 7 - CYAN

Figure 1.6 ERTS-1 Image of the Los Angeles Basin
 Printed to Emphasize Urban Land Use
 Features

2. THE ECONOMIC VALUE OF ERS INFORMATION

The only tangible products of a space-based ERS system are hard copy photographic prints, computer compatible digital tapes, and data collected by earth-based data collection platforms (DCPs) and relayed to ground stations by a space-based data collection system (DCS). These products have little intrinsic economic value aside from that derived from the interesting pictures that one might buy to hang on a wall. Thus, ERS data are not, in themselves, commodities that possess economic value. ERS data have to be interpreted, analyzed, for each individual user area, for each application. The interpreted, analyzed data, called information, then may, or may not, be of value: the value of information derives from the economic consequences of decisions or actions taken because of, or modified by, its use. Specifically, the information itself does not modify the production, distribution or consumption of economic commodities, but actions taken in light of new or better information can. |

The step of transforming data into usable information is yet the most challenging step in the ERS program; its precise requirements to meet user needs, and the cost of doing so are still to be fully understood and demonstrated. However, enough results of ERTS-1 investigators are in to allow a comprehensive assessment of the potential of these data for user applications, assuming that further investigations and demonstrations will fully close the gap between ERS data and user information needs.

In Kansas, for example, farmers used to plant winter wheat as a ground cover crop and plow it under in the spring in order to raise summer crops. The increased price of wheat due to the Russian grain deal, however, has recently led many farmers to harvest their wheat instead. The decision which the farmer makes is aimed at maximizing his personal gain. However, good decisions made by farmers are also good for consumers. If, in fact, there exists a potential shortage of wheat, this can result in higher wheat prices. By harvesting his wheat crop rather than plowing it under for summer crops, the farmer can take advantage of the higher price and, at the same time, keep the price from going even higher by adding his wheat to the total wheat supply.

The extent to which the farmer can make the correct decisions is a function of many variables, one of the most important of which is the accuracy of the current annual crop

forecast. Improvements in this forecast can affect not only the production of crops, but their distribution as well. Distribution is a decision between the alternatives of consumption today versus storage for future consumption; or a decision to export versus storing it for domestic consumption. Distribution decisions are made by investors who also want to maximize their personal gain; but again, in a competitive market, decisions based on better information result in more stable agricultural prices and benefit society in general.

Similar decision processes are ongoing in forestry management, water management and throughout industry. In each case, improved information provides a capability for better decision making that can benefit both the decision maker and society as a whole.

2.1 The Attributes of Information

What makes information derived from one source of data more valuable than information derived from another source? All forms of information possess certain attributes (or characteristics) that determine their economic value. These attributes are both economic and technical in nature and are of five generic types:

1. *Cost* - Cost is an economic attribute of information. Information that costs too much to obtain, for example, due to technical limitations, is of zero economic value.
2. *Accuracy* - Accuracy is a technical attribute of information that expresses the extent to which data (inputs to information) are correctly interpreted. Information loses value as its accuracy is decreased. At some point, information substitutes take over and the information loses all economic value.
3. *Completeness* - Completeness is a technical attribute of information that expresses its fulfillment of the total information requirement; for example, acreage information but not yield information as inputs to a crop forecast.
4. *Dependability* - Dependability is a technical attribute of information that relates to its consistency from sample to sample. If information is not dependable, then even when it is good, its economic value is not as high as it might be for dependable data of the same accuracy.

5. *Timeliness* - Timeliness is a technical attribute of information that relates to its period of availability. Information that is available after a decision is made is of little value to the decision maker.

In order for certain information to have increased economic value over alternative information, at least one of its attributes must be improved. Information with the same technical attributes but lower cost, for example, has the value of cost savings. Other information may have the same or higher cost but, because of improved technical attributes, allows improved decisions to be made, thus obtaining added value. In some instances, the technical attributes of information are such as to make it unique for certain applications.

An important concept to note is that information possessing a specific set of attributes can always be substituted for other information if the attributes of the other information are of equal or lower quality. If this is not the case, however, it does not necessarily prevent the substitution. In the latter case, it is the attribute requirements of the application that determine whether or not a substitution is possible.

Consider the case of ERS' satellite images versus high-altitude aircraft images. The aircraft images may have higher resolution but also higher cost than the satellite images. Thus, the satellite images would clearly be preferred for applications where their resolution is sufficient, other things being equal. For applications with higher resolution requirements, the aircraft images must be used. On the other hand, it is quite possible that, other things not being equal, the other attributes of the alternative information sources will affect their relative value and, hence, the selection.

2.2 Equal Capability Benefits

At the present time there is considerable demand for earth resources survey information which, in many instances is being met by aircraft surveys.* For each area of demand, there is a specific set of *technical* attributes required of the information. Wherever ERS satellite information can meet these

* For a documentation of the Federal activities and demand in related areas see Office of Management and Budget, Report of the Federal Mapping Task Force on Mapping, Charting, Geodesy and Surveying, July, 1973, U.S. Government Printing Office, Washington, D.C.

requirements, a simple cost test is applied. If the satellite information (fully processed) is less costly than the alternative information source, the satellite information can be substituted for the alternative source and will result in a cost savings if exactly the same quantity of information is supplied from either source.

From the point of view of the application, both data sources satisfy the technical requirements and any excess capability is unused. Thus, since exactly the same things are done given either information source, the cost savings obtained are referred to as an equal capability benefit. This case indeed occurs if, for example, the State of New Jersey wants to make a 1975 land use map. One and only one set of imagery, taken in 1975, may be required to do the job.

2.3 Increased Capability Benefits

More often, when one information source is replaced or supplemented by another with similar technical attributes but lower cost, the activity level, that is, the amount of information demanded, increases. This is illustrated in terms of standard economic theory as shown in Figure 2.1. If the price of information is reduced from P_1 to P_2 , the quantity of information demanded increases from Q_1 to Q_2 . If, in fact, the quantity demanded does not change, the demand is said to be

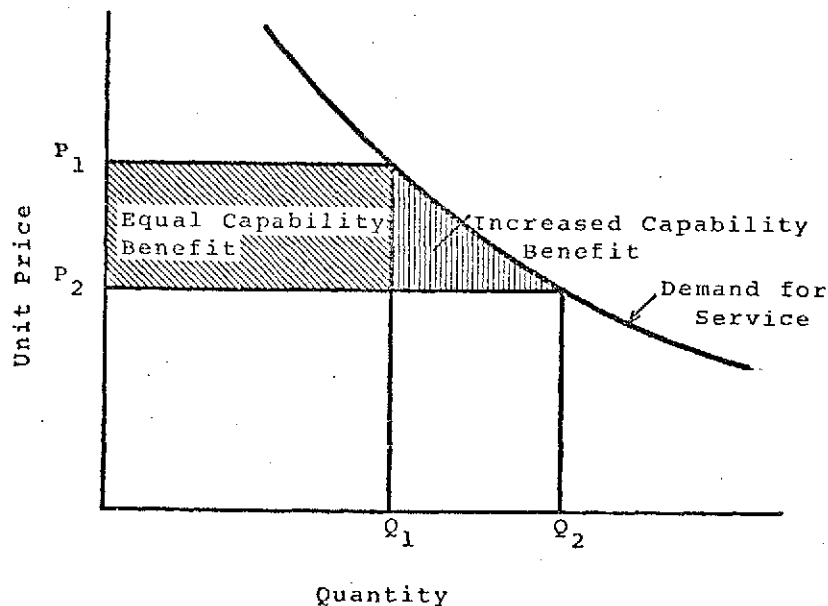


Figure 2.1 Equal Capability and Increased Capability Benefits

perfectly inelastic. But since most demand functions exhibit some elasticity resulting in increased activity due to lower price, the benefit resulting from the lower price includes both an equal capability part, due to cost savings at the previous activity level, and an increased capability part due to the value of the improved information. The increased capability benefit represents the difference between the value of this information to users and its cost.

Measuring the demand function for information, or even its elasticity (slope) at the current market price, can be a difficult task. However, many agencies operate in such a manner so as to spend their budget. In these cases, the demand for information can be established on the basis of the "equal budget" assumption. In the simplest sense, this results in a unit elasticity demand curve for information or one for which total expenditures for information are constant and independent of the price. Generally, however, it is the total agency or organization budget that remains constant, not just that part used to acquire information. Thus, it is necessary to evaluate the effect of a price reduction in one (often small) component of a total program on the activity level of that program assuming a constant budget. For many of the benefits reported in this assessment, this has been accomplished and the total benefits attributable to an ERS system are given in terms of a cost savings or equal capability part, which is a lower bound of the benefits, and an increased capability part.

One "budgetary" paradox can arise if the demand elasticity for information is greater than unity. In this case, the total expenditures for information acquisition actually increase due to a reduction in price because the price reduction causes a large increase in the amount of information demanded. But despite the fact that total expenditures increase, there is still a net benefit attributable to the price reduction. This benefit consists of the two components noted (equal capability and increased capability).

2.4 New Capability Benefits

Equal capability and increased capability benefits arise only in cases where information of the ERS type are gathered and used today or will be (due to legal and statutory requirements) in the near future. For many applications of ERS-derived information, there is no such current activity. This may be

due to either technical--current data gathering systems lack the capability necessary--or economic--the cost of using current data gathering systems is too high--reasons. Thus, the introduction of ERS-derived information for these applications represents a new capability not presently available.

It is not possible to obtain *directly* the demand for information for a new capability application because no such demand currently exists. Instead, it is necessary to compute the demand for information and the effect of information on the production function of a commodity in an economic system context. Information which enables production of a commodity at a lower price is of value to the producer. In the event that a monopoly market exists, the producer can increase his profits by reducing the costs of production while maintaining a constant price for this product. In the case where competition exists in the marketplace, the production cost savings are passed along to the consumer in the form of reduced commodity prices. In the latter case, the producer might or might not benefit from the new information, but he must make use of it to remain competitive.

Figure 2.2 shows the benefits resulting from improved information in the production of a commodity. Supply function S_1 shows the producers current marginal cost of production. If new information enables a change to supply function S_2 , the resulting benefit is the total shaded area. The monopolist could hold the price constant at P_1 and increase his profit by the amount shown as cost savings. Whether, in fact, he would do this or change the price in order to increase consumption depends on the elasticity of the market which determines if this is to his benefit. In a competitive market, much of the cost savings is passed along to the consumer and both the consumer and the producer benefit from increased consumption.

In turn, the availability of an entirely new capability or service may lead to entirely new demand sources or drastic shifts in demand functions as the service is introduced. This combined evaluation is shown in the ECON ERS case studies

Any assessment which deals with the value of information must address the five generic attributes of information. In the case of cost savings (equal capability and increased capability), a necessary condition for benefits to arise from the introduction of a new information source is that the new information at least meet the requirements of these attributes for the given application. In the case of new capabilities, derived by virtue of the new information, the economic value of the information is *limited* by these attributes as well as the economic potential of the application.

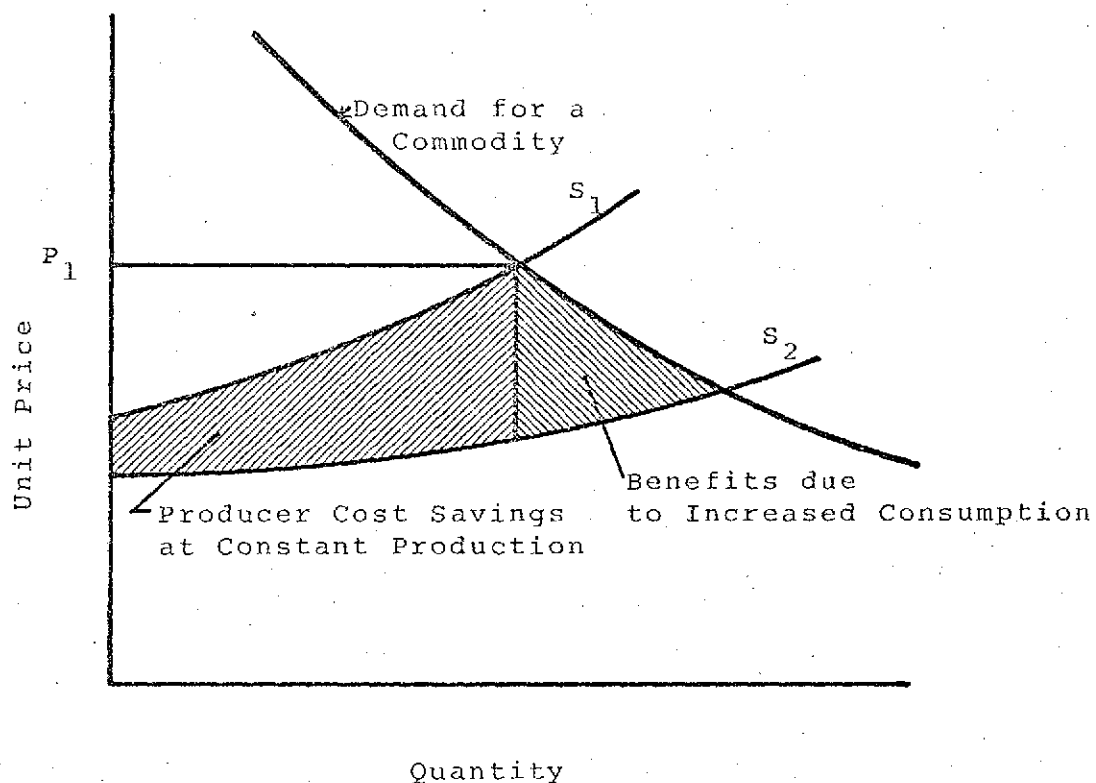


Figure 2.2 New Capability Benefits

This study does not include an assessment of the technical attributes of ERS-derived information. However, the assessment of measured benefits is based only upon applications of ERS information for which extensive ERTS-1 investigations have defined the limits of ERTS capability. The technical assumption that is made here is that the timeliness of information can be improved by the use of more than one satellite and by improved, demonstrated state-of-the-art data processing techniques.

Chapter 2 of the Source Document, Volume II, details the economic theory of ERS benefit estimation as applied in this study.

3. MEASURED DIRECT BENEFITS OF AN ERS SYSTEM

The purpose of this chapter is to document, in summary form, the answers to the first two questions posed in Chapter 1 of this summary; specifically, what are the measured direct benefits of an ERS system and how are these benefits distributed? Direct benefits, in the context of this study, mean benefits attributable to primary effects of an ERS system.

The approach of this study is to thoroughly review all previous studies of the benefits of an ERS system. These include, for example, studies by EarthSat-Booz Allen in the areas of agriculture, land use, water resources management, rangeland management, forestry, and environmental monitoring; the ERTS-1 investigation reports and the Agricultural Task Force report.* In reviewing those studies where benefits are claimed, in most cases, these claims are not accepted as accurate, measured benefits of an ERS system. Instead, these claims are either rejected or only accepted with reservation. Such reservations are fully reported in the Source Document; Volume II, and in Volumes III through X. In a few cases, it is determined that other studies have fully documented ERS benefits and these benefits are reported without change in this report as *measured* benefits. Table 3.1 lists for each resource management area, the specific resource management functions which yield measured benefits and shows the volume of this study in which these benefits are documented.

In addition to the measured benefits obtained through the survey of previous and ongoing studies, the data presented in this report are further substantiated by in-depth case studies performed by ECON. Three areas are dealt with in these case studies: agriculture, water management and land cover. These are summarized below.

3.1 Agricultural Benefit Estimates

Within the area of agriculture, an assessment of the value of ERS information to three application areas is explored:

1. benefits from ERS information in the distribution of agricultural goods in the United States based on information on the United States (inventory behavior),

* Wood, D. B., et al., "The Use of the Earth Resources Technology Satellite (ERTS) for Crop Production Forecasts", Task Force on Agricultural Forecasting, Goddard Space Flight Center, Draft Final Report, July 24, 1974

Table 3.1 Measured Benefits of an ERS System		
Resource Management Area	Resource Management Functions for Which Measured Benefits Are Presented	Reference (Volume)
1. Intensive Use of Living Resources: Agriculture	Part I: 1.2.1, 1.6.5 Part II and Part III	III
2. Extensive Use of Living Resources: Forestry, Wildlife and Rangeland	2.1.1, 2.2.7, 2.4.1, 2.4.3, 2.4.5	IV
3. Inland Water Resources	3.1.2, 3.1.4, 3.2.1, 3.2.2, 3.2.3, 3.3.1, 3.3.2, 3.4.1, 3.4.2, 3.4.3, 3.4.4, 3.6.1, 3.7.1, 3.9.1	V
4. Land Use	Benefits in this area are not distinguished by RMP.	VI
5. Nonreplenishable Natural Resources: Minerals, Fossil Fuels and Geothermal Energy Sources	5.1.1, 5.4.1,	VII
6. Atmosphere	6.1.2, 6.9.1	VIII
7. Oceans	7.4.3, 7.5.1, 7.5.2, 7.5.3	IX
8. Industry	None measured	X
*See Table 1.1a for a summary of the magnitude of these benefits.		

2. benefits to the United States in the production of agricultural goods, based again on information on the United States only, and
3. gains to the United States in world trade of small grains, with a particular emphasis on import/export decisions.

The objective of each of the above investigations is to measure ERS benefits "directly." In the case of distribution, a specific economic sector model of the agricultural economy in the United States is formulated and econometric estimation procedures used to assess the value of existing versus improved information. The results of this exercise indicate that an ERS system will lead to likely annual benefits of about \$32.9 million dollars per year for *wheat only* once these data are gathered with assured continuity of coverage. These may be as low as \$12.4 million under very conservative assumptions and as high as \$247.2 million under very optimistic assumptions. *

In the case of production benefits, the effects of better, more accurate information on the supply of crops are analyzed. The benefits estimated for an ERS system based on United States information only are less pronounced than production effects that might be derived from a worldwide ERS information system. Importantly also, the benefits will be different depending on the frequency and timeliness of the information provided for either distribution or production decisions in the United States. These areas are not well defined, as yet, and therefore, these benefit estimates concentrate on United States information and United States decisions domestically only, assuming the present frequency and timeliness of forecasting but with improved accuracy.

Finally, integrated with production effects is an analysis of benefits to be derived in United States net export trade, for wheat and soybeans. The hypothesis in this study is that ERS information coverage will be accessible to all countries on a non discriminatory basis.

The integrated production, distribution and net export benefits from ERS information are estimated to range from \$106 million to \$549 million per year for *wheat and soybeans only* (see page 3-9).

*See Table 3.3

The investigation into the value of improved (ERS) information in the markets for agricultural commodities is summarized here in two parts. The first part is an overview of the integrated agriculture case study effort; the second part is an overview of the agriculture distribution case study; the results and conclusions focus on the economic importance of improved crop forecasts in the domestic commodities market, in U.S. exports, and on government policy operations. These case studies are discussed in greater detail in the Source Document, Volume II and Volume III (Parts II and III) of this report.

3.1.1 Agriculture Case Study on Production, Distribution and Net Export Effects of Improved, ERS, Information

The purpose of this study is to show the effects and benefits of improved ERS information on the United States agriculture sector, including in particular production, distribution and net export effects. The benefits of improved ERS information are looked at in a systems context.

To measure the effect and value of improved information in the United States agriculture sector, the following four broad study tasks are addressed:

1. Foremost, to measure the influence of crop forecasts and net export demand on domestic agricultural commodity prices. To do this it is necessary
2. to specify the economic structure of the agricultural commodity markets and how information enters this market. Then,
3. to develop an empirically supported structure from which to assess the market impacts of policy actions and
4. to provide information needed to weigh the benefits of improved crop projections to society, and to identify linkages and guidelines for an analysis of world commodity markets.

The subsystems and issues encountered in the case study are illustrated in Figure 3.1. As can be seen from that flow diagram, the critical and immediate entry of (government) crop production forecasts is through their impact on market expectations of spot prices in the future. Once the improved ERS information enters the agriculture system through these expectations, it has effects throughout the

Complex as the effect of improved information on United States agriculture is, the overall investigation can be reduced to a few major policy variables considered, which include more than just crop forecasts by USDA. This analytic "bottom line" of the study, the major policy variables considered, is illustrated in Figure 3.2. The dotted lines represent indirect connections between associated variables. The solid lines in Figure 3.2 denote direct impacts free of intermediate actions or transformations.

As can be seen from Figure 3.2, crop forecasts enter the futures market directly as a driving force behind market expectations. These forecasts in turn impact the cash market, and physical flow of crops, indirectly through the influence of futures prices on the spot market.

The empirical objective of the case study was to measure the timing and responsiveness of domestic prices to improvements in crop forecasts (reduced error variability), and changes in the international food situation.

Among the market factors considered in the study are domestic consumption, net exports, government stockpiling, domestic and foreign production, stock adjustments in the private sector, government parity price operations, commodity substitutes and complements, and general economic conditions such as the availability of credit and rates of inflation on commodities.

The full, simultaneous interaction of these variables, and the impact of improved ERS information in this system, is set forth in the main body of the case study (Volume III, Part III). The evaluation of the technical capabilities of an ERS system to improve present crop forecast accuracies was not part of this economic study. Rather, the study used the findings of the Agriculture Task Force Report in "The Use of the Earth Resources Technology Satellite (ERTS) for Crop Production Forecasts", final draft, July 24, 1974.

The monthly forecast errors by USDA for the annual winter wheat crop are shown in Figure 3.3 (1968-1972, April through September). The final errors, at completed harvest, are about 2.5% for the annual crop estimate. During the growing season, month-by-month USDA harvest measurement errors are about 7.5% for winter wheat. The limit of ERTS accuracy for "at harvest" measurements is 2 to 2.5% as indicated by the Task Force

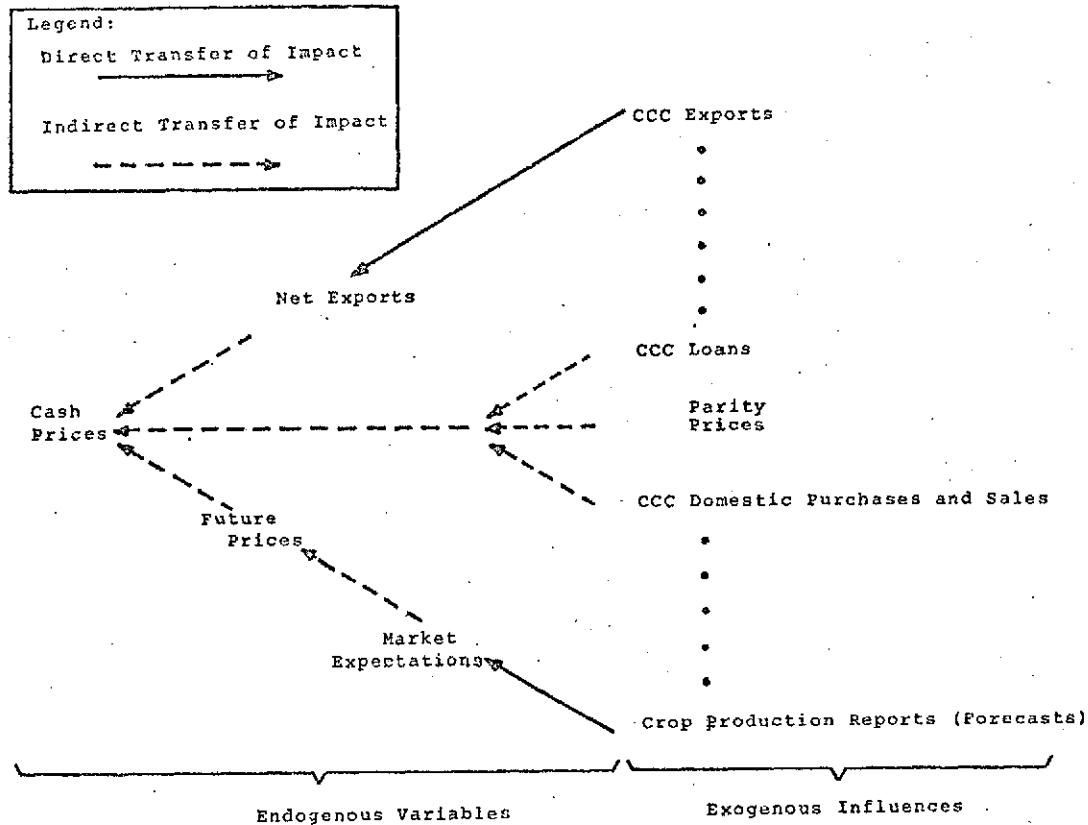


Figure 3.2 Exogenous Influences on Spot and Futures Prices (Source: ECON)

Report on Agricultural Forecasting. This accuracy will not vary much throughout the harvest season (unlike the USDA annual crop forecasts). Since ERS measurement is not subject to the effects of varying sampling errors, ERS systems promise to improve month-by-month harvest estimates substantially, when integrated into the USDA crop forecasting system.

The results of this technical evaluation and the empirical results of the case study on the structure and interactions of the U.S. agriculture sector using improved crop forecast information, provide estimates of benefits to society derived from ERS information. These benefits reflect 1973 prices and quantities and are measured in the tens of millions of dollars for both soybeans and wheat. The economic results are summarized in Table 3.2.

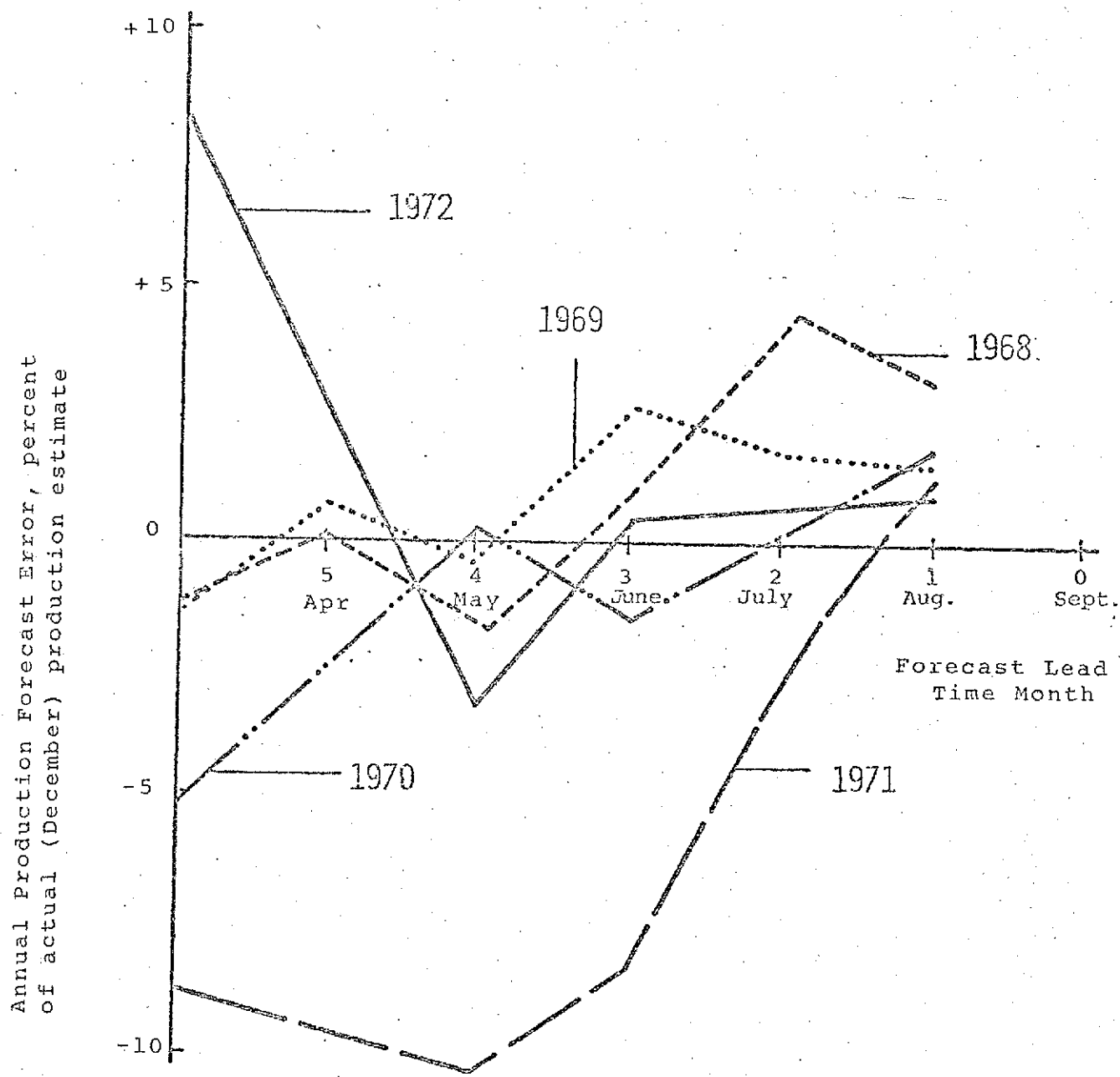


Figure 3.3 Published USDA-SRS Forecast Accuracy
Winter Wheat-Total Annual U.S. Crop

Table 3.2 Estimates of Annual ERTS Benefits Based on a Reduction in Crop Production Forecast Error Variation as Determined by Agriculture Task Force Report		
Crop	Annual Benefits, \$ million (1973)	
	Lower Bound	Upper Bound
Soybeans	71	337
Wheat	35	212
TOTAL	106	549
The data sources and assumptions used for estimating these effects and benefits are numerous and they are fully listed in Volume III, Part III of this report.		

The upper bound estimates given in Table 3.2 derive from using expected values of the estimated model parameters. The lower bound estimates derive from the extremely conservative approach of using 20 pessimistic values for all of the estimated model parameters. The lower bound estimate is even more conservative because of the following factors:

1. The estimation period for model parameters was mainly the 1960's during which period the U.S. market was not subject to foreign demand fluctuations to the extent that it presently is.
2. The government is now playing a less active role in price control.
3. The model estimates direct benefits only; secondary benefits such as released investable funds, for example, in the futures market, and induced benefits, for example, by price changes, are not included.

It is the lower bound of benefits in wheat and soybeans only that is reported as the lower bound of increased capability benefits in Table 1.1a.

There are, however, benefits to improved ERS information also as regards government policy and decision; these are not measured and reported in Table 3.2. For example, a common domestic objective of the government, operating through the CCC*, is to ensure a parity price for certain agricultural commodities such as wheat. The basic

* Commodity Credit Corporation, an agency of the U.S. Department of Agriculture.

operating rule for the CCC is to purchase a commodity when the market price threatens to fall below parity and sell the commodity when prices have surged beyond some predetermined upper limit. These actions by the government serve to increase demand in the former case and increase supply in the latter. The results in turn exert upward or downward pressure on prices, respectively.

Market prices, however, also reflect expected demands and expected supplies. Because crop forecasts, and therefore expected supplies, change from month to month as the harvest draws near, the government may be buying one month and selling the next in response to changes in market expectations owing to changes in crop forecasts; or they make export and import decisions based on these expectations.

To the extent that forecast errors manifest themselves in spurious price movements, the government will buy and sell the affected commodity to keep its price within bounds. Thus the government acts to insulate the market from forecast "noise". Obviously, if the forecasts were perfect, the government still may enter the market to offset any demand-supply imbalance *vis a vis* desired prices. ERS information of course will not alter these operating rules. The impact of ERS in this context simply will be to reduce the "noise" the government must filter from the system. Thus, ERS improved forecasts may exert a passive beneficial influence on government operations. However, ERS noise reduction may also actively enhance government policy operations. Every reduction in market noise only improves the government's view of the market and therefore helps the government design and implement better and more efficient agricultural policies. Again, no such benefits have been included, quantitatively, in this report.

3.1.2 Agriculture Case Study on Distribution Effects of Improved, ERS, Information

This case study looks at a very specific subset of the impact of improved ERS information in United States agriculture: the inventory holding pattern of wheat crops with today's accuracy of crop production forecasts and estimates, the change in these inventory holding patterns with improved, ERS, information and, finally, the benefits to society of such changed inventory patterns. This case study is, therefore, a part of the larger effort to evaluate the benefits of an improved agriculture information system that uses ERS satellites.

The results of this case study are closely related to the lower bound of benefit estimates reported in the previous broader agriculture case study: this case study mainly concentrates on the physical effects of improved ERS information in distributing agriculture crops, more specifically wheat.

The theory and measurement methods developed in this study are specifically designed to measure information effects on United States (domestic) agriculture crop distribution. These methods developed and used are therefore not dependent upon the detailed technical source of the information improvement. In our context this improvement is given by ERS information. The primary emphasis in this case study is placed upon establishing practical evaluation procedures of general applicability, firmly based in economic theory.

The basic logic of the case study is simpler than its many details may lead one to believe. Grain production is taken to be exogenously given, but subject to random shocks obeying a (possibly complex) stationary stochastic law. Production in any period can be allocated to consumption (including use in the production of other goods) or additions to inventory. Inventories are determined by profit-seeking competitive agents, who base their decisions on forecasts of forthcoming grain harvests. In order to determine their current inventory levels, these agents must anticipate the future inventory levels as well as future harvests. They do this by assuming that all inventory holders understand the underlying demand and marginal storage cost relationships, and hence they in effect look for a market clearing set of spot and futures prices.

The primary effort of the case study is devoted, in terms of time at least, to implementing the analysis for the case of United States *domestic wheat distribution and consumption*. This effort involves new estimates of a demand function for wheat and of a cost of storage function. As far as we know these represent a very significant improvement, in terms of economic techniques, upon studies available in the literature.

Another important component of the implementation effort is a Monte Carlo simulation of the wheat spot and futures markets. Since inventory adjustment is the point at which information is used in this analysis, it is necessary to have a model of market determinations of wheat inventories. Market equilibrium can be calculated from the empirically estimated parameters as a function of forecast harvests only if the carry-over horizon is known. That is the date in the future at which it is expected that the inventories of the grain in question will be completely depleted. Normally, the point at which the flow of newly harvested grain is beginning to swell is in June. In our analysis we show how this horizon can be determined by the solution to a certain non-linear programming problem, the parameters of which include the forecast harvest levels, which are variables with random errors. To obtain the distribution of carry-over horizons from postulated distribution of forecasts by analytic

methods is not feasible, and hence the operator of the wheat market was simulated in this case study by computing the carry-over horizon as well as such related variables as spot and futures prices at each stage. The model is easily adaptable to other markets. We are not aware of any similar study in the literature.

Given these facts, and having empirically estimated the demand and marginal storage cost functions, we describe the functional dependence of inventory decisions produced by the market system and harvest forecasts. We then determine the relationship between measurement errors, as leading to forecast errors, and the average amount of variability to be expected in the grain consumption flow. Variability is a source of disutility -- marginal quantities of grain are more highly valued when consumption levels are low than when they are high, as reflected in the demand curve. Hence we can calculate the loss in value due to measurement error, and the gain due to its amelioration.

The empirical pieces of the study are put together in the Source Document, Volume II, and Volume III. The results are shown to depend critically on the accuracy of current and proposed measurement techniques. Surprisingly, these pieces of information were not readily available.

Available studies, such as that by Gunnelson, Dobson and Pamperin* tend to focus on forecast error, which is a compound of nature's variance and variance introduced by the measurement system. Statistics on forecast error contain, of course, some information constraining measurement error, but drawing implications from them requires very strong assumptions as to the underlying model. For purposes of the case study these data are not suitable.

In their study of the value of improved statistical reporting, Hayami and Peterson encountered much the same sort of problem.**

* Gunnelson, G., W.D. Dobson and S. Pamperin, "Analysis of the Accuracy of USDA Forecasts," American Journal of Agricultural Economics, November, 1972, pp.639-645.

** Hayami, Yujiro, and Willis Peterson, "Social Returns to Public Information Services: Statistical Reporting of U.S. Farm Commodities," American Economic Review, March 1972, pp. 119-130.

In their Table 1 (Ibid, p. 125) they present data on "typical sampling error" in major U.S. farm commodities prepared by the Statistical Reporting Service, U.S. Department of Agriculture. The methods by which the USDA calculated these statistics are not specified, nor are definitions of the usual sort provided. By making some assumptions, however, we use these data as the basis for plausible values in exploring our own results. Again, we would stress that these figures should be regarded as far-from-well-established.

The results described in Table 3.3 indicate both the possibility of very substantial gains from reducing measurement errors in the crop forecasting system and the sensitivity of the results to the values of current and potential measurement error variances.

Even relatively conservative assumptions (average demand elasticity for wheat, zero population growth, better current measurement, smaller percentage gain in accuracy) seem to suggest a rather substantial potential for gain from improved measurement accuracy (\$32.9 million per year). However, the great sensitivity of the results to variations in percentage accuracy, indicate that to obtain reliable estimates further efforts must be made to discover more about current and potential measurement error. Allowing for these variations, the benefits may vary between \$20.6 million a year up to \$82.4 million a year for wheat distribution.

All of the calculations reported in Table 3.3 and the case study are directed toward evaluating a reduction in measurement error. However, as our discussion of forecasting in general in Volumes II and III makes clear, the timeliness of information also importantly affects its value. This would be expressed in this model as reduced availability lag. This is an area in which satellite technology clearly promises substantial improvement, and it is one which may even have the potential for more substantial gains than found for measurement error reduction. Our estimates, suggest rather substantial month-to-month variability in ideal forecasts, nature's randomness. By reducing the availability lag by one month, we, in effect, eliminate one month's worth of variance. The value of this should be comparable to that of a similar reduction of variance due to measurement error improvement. The precise time lag between gathering ERS information and the actual forecast made has not been identified with sufficient precision (one month, one week?). Thus benefits of this latter improvement have not been included in Table 3.3.

Table 3.3 The Value of ERS Information in Distribution of Wheat for Domestic Consumption

Price Elasticity for Wheat Demand <u>a/</u>	Benefit for Given Value of α (95% confidence limit for percentage error in monthly harvest measurement), \$ millions (1973)		
	7.92% <u>e/</u>	10% <u>f/</u>	15.84% <u>g/</u>
-.10 <u>b/</u>	61.8	98.6	247.2
-.30 <u>c/</u>	20.6	32.9	82.4
-.50 <u>d/</u>	12.4	19.7	49.6

a. United States domestic demand for all wheat, except as noted.
 b. EarthSat estimate in recent report to U.S. Dept. of the Interior
 c. Likely current price elasticity for 1974
 d. The basic estimate obtained by the authors for the price elasticity of unconditional demand for wheat (1971 data)
 e. α derived from 2.2% error in annual harvest (May crop measurement of error Winter Wheat).
 f. Approximate weighted average value of α for all wheat.
 g. α derived from 4.4% error in annual harvest (September crop measurement error for Spring Wheat).

The weakest links in the study are probably the early ones,, for example, the very first one, which assumes grain production is exogenously given. We have argued in the text that a good case can be made for taking this assumption as a working hypothesis. Nevertheless, we should expect the results to be altered by the introduction of an endogenous production decision model of farmer behavior. That smoothing out of consumption and hence price movements over time is likely to have value to farmers should be obvious, given the history of the search for farm price stability. This is precisely what was done in the integrated agricultural case study reported in Section 3.1.1.

The second link shows a related weakness, in leaving out a set of decision makers. It is noted in the case study that production is allocated not simply to consumption and inventory changes, but also to net exports, and in fact, the empirical parameters of a very simple model of export determination importantly influenced the numerical results, as summarized in Table 3.3. A final important group of agents is omitted at the third link at which it is assumed that grain inventories are determined by private entrepreneurs. In fact, certainly in the United States over the past twenty years, the government has been a major agency determining the quantity of grain in inventory.

How greatly the absence of these decision agents from the model affects the results was part of the integrated agriculture case study. As the results of that study indicate, the \$32.9 million benefit estimated for domestic wheat distribution effects is borne out, relatively, by the \$35 million estimate for similar effects in the integrated agriculture course study.

3.2 The Ad Hoc Water Management Study

In order to evaluate the potential value of ERS information in water management, an ad hoc case study was performed on the Feather River System. This study is documented in detail in Volume V. The activities that benefit from improved ERS information are shown in Figure 3.4 . With or without ERS information, the Oroville Dam is managed in such a way as to insure, with virtual certainty, the absence of flooding. Better water management will not show up directly in terms of flood control, but will be affected in the other economic activities shown. Therefore, the value of ERS information in flood control of the Feather River can be treated as zero.

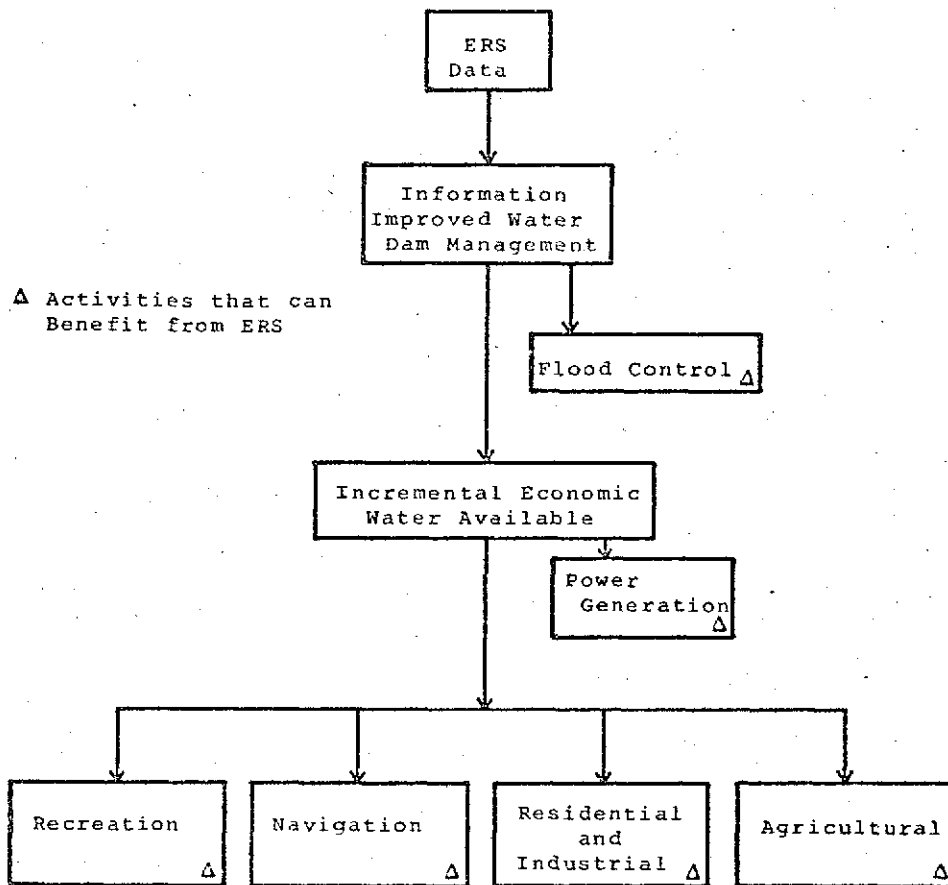


Figure 3.4 Activities that Benefit from Improved Water Management

An accurate prediction of the monthly inflow rates for the Oroville Reservoir is necessary for better management of the Oroville Reservoir and the California Water Project. Currently, predictions are provided on February 1st for the entire water year (October 1 - September 30) and updated monthly through May 1st. The April to July forecast results for the October 1972 to September 1973 water year are shown in Figure 3.5

Several interesting phenomena are pointed out in this figure all of which indicate the potential need for more and better information on which to base forecast runoff. From the diagram, it is apparent that forecast accuracy *does not improve*

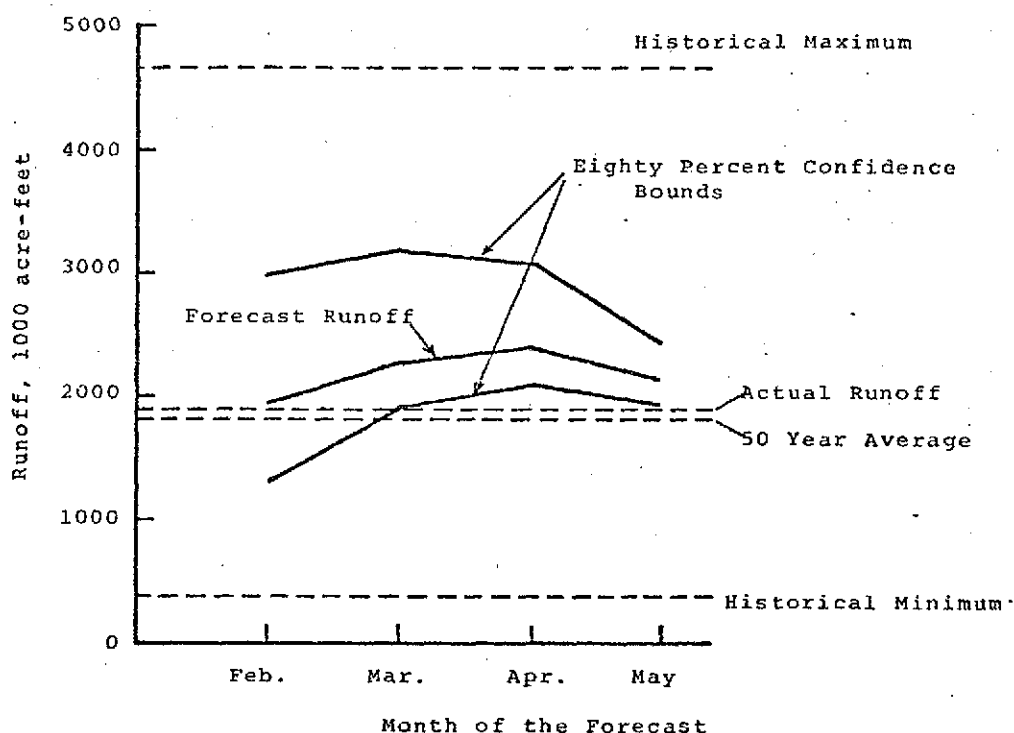


Figure 3.5 Unimpaired Runoff into Oroville Reservoir for the Period 1 April 1973-31 July 1973: Predicted vs. Actual, Without ERS Information

from month to month as might be expected. Also, it is seen that the eighty percent confidence bound diverges from the actual runoff with each new forecast up to April and apparently does not begin to converge until actual runoff data are available.

The time at which water is delivered plays an important part in the determination of its economic value. Thus, it is necessary to know not only the amount of water which will enter the reservoir during a given interval but also the schedule at which this water will enter.

Current predicting techniques provide accuracy to within approximately twenty-five percent for both short term and long term predictions. The uncertainty of the "correctness" of these predictions is an important factor in the supply of

economic water* and can in itself either provide significant quantities of economic water or for very poor predictions, limit the supply drastically.

If the introduction of ERS data can cut the information and modeling error by 20% then an additional 110,000 acre-feet of economic water are available. That an ERS system can perform to this degree appears to be supported by the recent reports of a number of ERS principal investigators. Some of these principal investigators are Alexander, Burgy, Cooper, Hoffer, Holgren, and Meier. A description of their reports is given in Volume 5, Appendix G. However, we did not perform a technical assessment of the likely capabilities of ERS.

From another standpoint, it can be stated that ERS will improve forecasting accuracy. ERS has a much larger geographic area of coverage than is practical with aircraft. Since the sampling error is inversely related to the square root of the geographic area of coverage, a much larger area coverage will significantly reduce the sampling error. In addition, in the EarthSat-Booz Allen Report on Water Management, estimated benefits presented in their tables are based on 25%, 50%, and 75% increase in forecasting accuracy.

The remainder of this study is devoted to determining the value of the added economic water.

Agricultural studies analyzing the value of water for irrigation were conducted by Brown and McGuire** in 1967. Using demand functions fitted to two different sets of data, one from the California study for districts served by the Kern County Water Agency (KCWA), they obtained estimates of approximately \$19 per acre-foot for the first set of data and \$15 per acre-foot for the function fitted to the farm budget

* Economic water is water which can be used for economically beneficial purposes, for example, irrigation or power generation. Dumped run off water which cannot be put to any use downstream is of no value, hence it is not economic water.

** Brown and McGuire, A Socially Optimum Pricing Policy for a Public Water Agency, Water Resources Research, Vol. 3; No. 1, 1967, pp. 33-43.

study. For the Feather River Area the total equivalent unit charge per acre-foot is \$13.46, which is low in comparison to the rest of the state.

The value of 110,000 additional acre-feet of water at \$13.46 per acre-foot is \$1,480,000 per annum. Adjusting for the movement of crop prices since 1967, when the value of \$13.46 per acre-foot of water was calculated, an increase of 40% for the value of water is conservative. The annual benefit from increased water for irrigation and other non hydroelectric power purposes is then determined to be \$2 million in 1973 dollars.

The other reservoirs in the California State Water Project have combined capacity that is approximately two-thirds of Lake Oroville. Therefore, an additional \$1,380,000 per annum of irrigation benefits in California is arrived at in the Case Study. Based on the EarthSat Report on Water Management (p. 99), the potential net benefit for irrigation activities in California is 40% of the total for ten Western states. An estimate of the total benefit from additional irrigation of \$8,580,000 per annum is determined on this basis.

To calculate the value of 110,000 acre-feet of water for power generation, which can be obtained in addition to its value for irrigation, it is necessary to (a) determine the amount of kilowatt-hours (kwh) that can be generated by this amount of water and to (b) determine the incremental value per kwh. Potential hydroelectric power is a function of the volume of water and the average height of that water. Given the power generation parameters of Oroville and Thermolito, an acre-foot of water at Oroville-Thermolito is equivalent to 658 kwh of electricity. The total amount of additional hydroelectric power is therefore 72.4 million kwh. The annual value of this hydroelectric power based on 1973 energy prices is therefore estimated to be at least \$1,450,000. Extending this benefit to other United States hydropower systems where ERS systems can be of use yields an annual benefit of \$42 million.

By combining the value of added economic water for irrigation and hydroelectric power generation, a lower bound estimate of annual benefits attributable to improved (ERS) information of \$50.6 million is obtained.

3.3 The Land Cover Case Study

The purpose of this study is to examine the economic potential (cost savings) of an ERS satellite system in the development, updating and maintenance of a nationwide land cover information system in the post-1977 period. As envisioned in this study, the national information system must be capable of satisfying at least the land cover information requirements of all Federal civilian agencies under existing Federal statutes. The study examines several alternative acquisition systems for land cover data and the relevant information acquisition costs, including data processing and interpretation costs associated with each alternative. The study objective is to determine, on a total life cycle cost* basis, under what conditions of user demand (area of coverage, frequency of coverage, timeliness of information, and level of information detail) an ERS satellite system would be cost-effective compared to a non space-based system and, if so, what would be the annual cost savings benefits.

Major conclusions of this study are:

1. An ERS satellite system is cost-effective compared to an aircraft system for satisfying the expected level of demand for land cover information in the post-1977 period. This assumes a level of demand of six times coverage of the continental United States plus Alaska, each mapping mission to be completed within 60 days and the mapping information classified to Level II detail, (USGS - Circular 671 classification scheme) and more detailed coverage (Level III) of the same area once every five years. To satisfy this demand, the cost-effective system requires two active satellites in orbit. However, high and low altitude aircraft with ground survey teams are also necessary components of the data acquisition system for this level of demand.
2. A three-satellite system with high and low altitude aircraft and ground survey teams is cost-effective at an annual demand level of twelve times coverage of the U.S. at Level II, with each mapping mission to be completed within 30 days and Level III coverage of the U.S. once every five years.
3. In the post-1977 time frame, automatic (for example, computer) interpretation and classification techniques will be technically and economically preferred over manual interpretation methods.

* Life cycle costs are computed over the period 1975-1993 in 1973 dollars discounted at 10% to 1974.

4. At a minimum, the annual gross benefits (net cost savings and cost annuity for space system) attributable to a space-based ERS system over an aircraft-based system as a component of a nationwide land cover information system is \$53.5 million (1973 dollars). This benefit is based on a demand for land cover information of 6 times a year, 60 days, at Level II. If the demand level in the 1980s were to increase to 8 times a year, 45 days, at Level II, the annual gross benefits are \$62.6 million (1973).
5. The satellite configuration assumed for purposes of this analysis is not the optimum configuration to accomplish both the United States coverage mission and a global coverage mission at minimum cost. Further cost savings is possible by reconfiguration of the ERS system studied to meet global land coverage needs.

The study approach is shown in overview form in Figure 1.3 of Vol. VI, Part II. The analysis begins with projections of the demand for land cover information which each competing system must satisfy on an equal capability basis. For the purposes of this analysis *only demand which requires full target coverage is considered*. Thus, demand requirements which can be satisfied by a probability sample of a given target area have been excluded from this analysis.

The analysis of demand for remotely sensed land cover information focuses on four major characteristics of user demand: area of target, timeliness of information, frequency of update, and level of information detail. The target area refers to the percentage of the United States that must be covered to satisfy a specific demand requirement. Though actual user-desired targets vary continuously from small regions of the United States to the full United States, this analysis classifies user demand into one of four area requirement categories: 100%, 10%, 1%, or .1% of the United States. Timeliness of information (also called user time window) refers to the maximum allowable elapsed time (in days) during which the sensing of land cover information must be completed in order to satisfy the user. This important characteristic varies from one week to five years. The frequency of coverage refers to the number of times that targets of a given size, timeliness requirement and level of detail requirement are covered during one year. Note that the frequency of coverage is a composite of users who want repeated coverage of a given target area as well as users who want one-time coverage of targets of a given size which are geographically or temporally distinct. The level of information

detail reflects the scale required which, in turn, is determined by the type of information needed to fulfill the users' requirements. In this study, Level I information corresponds to a mapping scale of 1:250,000, Level II, 1:125,000 and Level III, 1:24,000.

Using the above four demand characteristics, a search was made of the existing Federal statutes that either mandate or enable Federal civil agency land cover mapping programs. An analysis of Federal legal demand for remotely sensed land cover information in the 1977 time frame (under existing Federal statutes) was made for the land use planning community and separately for all land cover users. Documentation of this analysis is presented in Volume VI. After eliminating overlapping data gathering requirements of the various Federal agency users, it is concluded that most of the Federal demand requirements for both user groups is for Level II information; the coverage requirement extending over the entire continental United States and Alaska land area at an annual mapping frequency of four times, seasonally, that is, within 90 days. The vast majority of Federal agency demand for full target coverage (non-sampling applications) arises from the land use planning community. No Federal requirements for Level I information, for either the land use planning community or other Federal land cover users, is identified.

Demands upon a national land cover information system will not be limited to Federal users only. A separate ECON study documents the need for earth resource management data from State, regional and local government units as well as the needs of the commercial and academic community. Quantitative estimates of the sources are highly uncertain. Therefore, this study explores the economics of an ERS system over a range of future demand levels from two times coverage of the full United States at Level II within 180 days to twelve times coverage of the full United States within 30 days.

On the supply side of the analysis, there are several alternative systems considered for the acquisition and processing of the land cover user-requested data. Each technical system is made up of two or more of three basic remote sensing components; namely an ERTS-type satellite, high altitude aircraft and a ground truth system (defined to mean a low altitude aircraft with ground follow up teams). These remote sensing components (designated S, HA and GT) are combined to form the several data acquisition systems indicated in Table 3.4.

For purposes of this analysis each of the two- and three-tier system alternatives listed in Table 3.4 has an implied priority ranking associated with the use of its constituent data acquisition systems. The priority ranking is defined by the ordering of the components of a given technology choice. For example, the S/HA/GT technology implies that in our analytical models the satellite component will satisfy as much of the user demand as is possible,

Table 3.4 Alternative Data Collection Systems for Nationwide Land Cover Information System	
Three-Tier Systems	Two-Tier Systems
1. S/HA/GT	1. HA/GT
2. 2S/HA/GT	2. S/GT
3. 3S/HA/GT	3. 2S/GT
	4. 3S/GT

consistent with its capability to meet the level of detail of the user information requirement, the user timeliness requirement and to overcome cloud cover problems. Whatever portion of user demand cannot be satisfied by the first tier is assigned to the second tier and so on.

A summary of the study results is shown in Table 3.5 and Figure 3.6. At a demand above six times full United States coverage per year, the space-based system is cost-effective compared to an aircraft-based system. The net annual benefit at this level is \$7.9 million. Since all benefits in this summary are jointly compared to the satellite program costs as shown in Table 1.2 (Chapter 1), the gross benefits at this demand level are \$53.5 million (net benefits of \$7.9 million plus systems cost annuity of \$45.6 million, all at 10 percent discount rate).

If a demand level is used that can be reasonably expected in the 1980s (8 times a year, 45 days at Level II) the corresponding net benefits are \$17.0 million, the gross benefits are \$62.6 million (including the two-satellite cost annuity of \$45.6 million).

3.4 The Distribution of ERS Benefits

The economic benefits of an ERS system are the sum of the private and governmental gains accruing from the use of satellite information for the appropriate management functions in earth resources. This section discusses how these benefits may be distributed, both with respect to the individuals, firms, industries and agencies which gain from using ERS information, and with respect to the timing of these gains in relation to launch date.

Table 3.5 Summary of Total Program Cost (1977-1993) to Provide Level II Mapping Information of Continental U.S. and Alaska Using Automatic Data Processing		
Annual Level II Coverage Frequency and Timeliness	Program Cost*, \$ millions (1973) discounted at 10% to 1974	
	Allowable Cloud Cover 0-30%	Allowable Cloud Cover 0-10%
Twice at 180 days each	488.5 HA/GT 646.9 S/HA/GT	616.3 HA/GT 779.2 S/HA/GT
Four times at 90 days each	613.3 HA/GT 701.7 2S/HA/GT	835.6 HA/GT 881.6 2S/HA/GT
Six times at 60 days each	815.6 HA/GT 758.4 2S/HA/GT	1137.3 HA/GT 984.4 3S/HA/GT
Eight times at 45 days each	1044.3 HA/GT 798.2 3S/HA/GT	1476.5 HA/GT 1129.5 3S/HA/GT
Twelve times at 30 days each	1548.3 HA/GT 997.9 3S/HA/GT	2168.3 HA/GT 1603.4 3S/HA/GT
Legend: S refers to an ERTS-type satellite HA refers to high altitude aircraft (U2) GT refers to low altitude aircraft and ground survey follow up teams		

Annual U.S. Level II Coverage Requirements, Multiples of continental U.S.

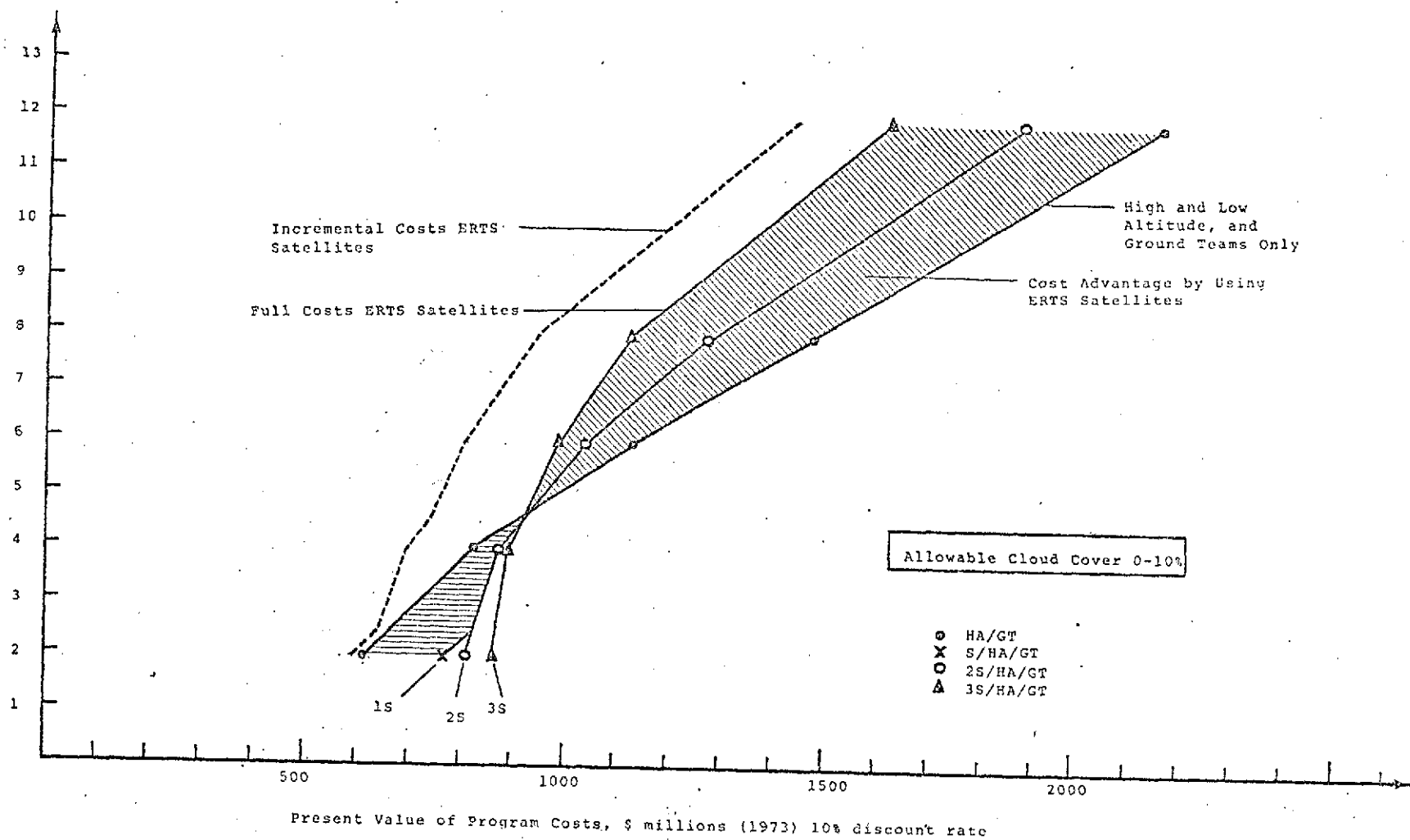


Figure 3.6 Present Value of Total Program Costs as a Function of Coverage Requirement for an Operating System between 1977 and 1993

Who gains? In the absence of a monopolistic body controlling the flow of data and information from the ERS system to the end users, it is very unlikely that any individual, or group of individuals, could achieve substantial gains at the expense of others. This is because information which is widely disseminated to the public by an impartial agency is not readily subject to economic exploitation. Any use of the information to achieve private gains is equally available to all potential users and, thus, these gains should result, through efficient management, in a net gain to society as a whole.

In the case of improved forecasts of agriculture crops, there is a need for careful organization of the manner in which such forecasts are released to the public to prevent one-sided gains from occurring (and also one-sided losses). The situation is similar to the effect on the major stock exchange of the release of key financial statistics. Discriminatory release of such valuable information must be guarded against to protect the public interest. The benefits shown in Table 1.1a are conservative estimates on the value of ERS information in eight application areas. These are mainly the value of information on the United States for United States uses. These estimates are arrived at with the ground rules as stated in Section 1.1, namely that the Federal Government will own and operate an ERS satellite system, including national ground stations and provide a data distribution mechanism that affords timely, non-discriminatory access to all data acquired.

With this non-discriminatory access to ERS data, the estimates of ERS information benefits will accrue to a whole range of economic sectors and regions in the United States. Land-cover information benefits will accrue to all states, public and private enterprises, producers and consumers. The same broad distribution of benefits will result in most of the other application areas: non-replenishable resources, the atmosphere, oceans, industry.

In the case of inland water resources, most of the water management benefits will accrue in the Western United States, where water is most scarce, and where snow cover is an important determinant of water runoff. ECON did an analysis of the likely distribution of ERS benefits in agriculture, again assuming non-discriminatory access to ERS data. Two cases are analyzed: First, in the initial years of operations of an ERS system benefits will accrue mostly in proportion to value added or sales, throughout the agricultural sector of the United States economy, including farmers and consumers. Secondly, in the long run, say after 10 years, the competitive effects in the United States agricultural sector make it likely that most of the measured benefits accrue to

consumers through dampened price movements and to farmers through increased "rent" and better production decisions. The initial, as well as long term distribution of benefits from ERS information in agriculture only are summarized in Table 3.6.

Table 3.6 Incidence of Distribution and Production Gains by Society from Improved Information in Agriculture Assuming Non-Discriminatory Data Access: \$250 million total (1985).						
Affected Industry	Gain, \$ millions (1973 prices)					
	Initial Years of Operation			Long Term		
	Dist.	Prod.	Total	Dist.	Prod.	Total
Tobacco Industry	10		10			
Food Industry	52		52			
Lumber Industry	3		3			
Forestry Industry	1		1			
Textiles	12		12			
Agriculture (All)	74	12	86	12	6	18
Agricultural Services	4	5	9			
Fed. Government Enterprises	5		5			
Real Estate	14	10	24	38	19	57
Agricultural Machines		2	2			
Chemical Industry		6	6			
Petroleum Industry		5	5			
Wholesale Retail		4	4			
Finance & Insurance		1	1			
Business Services		4	4			
Maintenance		1	1			
Households	25		25	150	25	175
Totals	200	50	250	200	50	250

4. THE VALUE OF CONTINUITY OF ERS SERVICE

This chapter provides backup to Question 3 in Chapter 1, viz, what are the economic benefits foregone in the event of a one-year gap and a two-year gap in ERS coverage providing at least the capabilities of an ERTS system? The benefits foregone can be expressed as the sum of two parts, the value of a continuing benefit stream beyond ERTS-B and the value of continuity of service in providing a more rapid build-up in the ERS benefit stream. Clearly, the value of a continuing benefit stream beyond ERTS-B depends upon the size and build-up rate of the benefit stream prior to and during the ERTS-B mission, and this in turn depends largely on the projected future of ERS systems. Thus, the mere assurance of a follow-on program beyond ERTS-B can and, we would expect, will affect the benefits derived directly from an ERS program.

At the moment, NASA is committed to launch the ERTS-B satellite, tentatively in February 1975. If ERTS-B fails to orbit and function properly, there is, of course, no backup satellite and ERS services will be interrupted. There exist, no doubt, many individuals and groups whose interest in the ERS Program is dampened by this uncertainty.

In this analysis, we assume that ERTS-B is successfully launched and activated as scheduled. The satellite is expected to last for two years, and there is every reason to believe that it will, but no guarantee that this is the case. In any event, ERS users face even greater uncertainty beyond ERTS-B: Will there exist a satellite to take over the ERS data gathering function when ERTS-B fails? Will it be successfully launched and activated? What happens if it fails? What comes after it?

In principle, a program of phased growth of some sort should interest the largest number of users. First, it is recognized that the ERTS satellite is a first-generation, experimental vehicle. But its potential usefulness, capabilities and reliability are now demonstrated. An abrupt advance to a more sophisticated ERS satellite without continuing the ERTS Program is fraught with uncertainties that could very easily overshadow its improved capabilities in the short-term. Thus, independent of the sophistication of the second-generation ERS system, there is value to a continuation of the ERTS Program, even into an overlap period. Second, it is clear that, until the risk of interruption of ERS service is removed, many potential users will choose not to make use of ERS data.

The effect of risk on a rational investor is a quantity that can be measured. It is well established that most individuals will pay, that is, forego profits, to reduce risk. For example, most people are not averse to obtaining as little as \$1.03 or \$1.04 for a guaranteed short-term investment of \$1.00. However, this would certainly be unacceptable if there were a 50% chance of getting \$0 back. In the latter case, a rational person would not invest \$1.00 unless, with 50% probability, more than \$2.00 were returned (with 50% probability of zero return). Conservative or risk averse individuals will insist on substantially more than \$2.00 return even on a very short-term investment particularly if the \$1.00 constitutes a large portion of his net worth. The amount beyond \$2.00 required to entice the individual into the zero-time venture is a measure of his cost of risk or, conversely, a measure of what the individual is willing to pay to reduce risk. Most successful investors are quite risk averse.

At the present time, the ERS Program contains a great deal of risk to the potential user. Will the program continue? Will there be gaps in service? Will the nature of the service change drastically? These risks impose a perceived cost on present and potential users that cause them to exercise this new (ERS) capability in only a very cautious and limited manner, thus foregoing many of its potential benefits. Elimination of gaps in ERS services will certainly reduce this risk and thus increase the benefit stream. Only a long-term commitment to continuity of service can create an environment in which full realization of the ERS potential as reported in this study will be possible.

4.1 Achieving ERS Benefits

It is necessary to take a brief look at where remote-sensing Earth-resources stands today and what factors can influence the rate at which the ERS benefit stream matures. The ERTS investigations to date have focused on a scientific evaluation of the general capabilities of an ERTS-type satellite. Can wheat, corn, rice, etc. be recognized? Can acreage be measured and to what accuracy? Can snow and clouds be differentiated? Can forest insect infestations be observed? Some transfer from scientific investigation to the user has occurred, but it is minimal compared to the ultimate potential. Part of the reason for this is the sequence of events that must transpire before this transfer can be accomplished.

First, after establishing scientific feasibility of an activity, for example, obtaining wheat acreage from an image, it is necessary to validate the results across many images, of many different areas, under differing meteorological conditions. A new set of questions, operational questions, must be answered. How dependable is the ERS system for this activity? With what reliability can wheat be recognized? What is the false alarm rate? How can recognition based on spectral signatures be extended to areas with little or no on ground observations? It may be possible to observe some phenomenon 100% of the time when it occurs but, because there may be a high false alarm rate, there is no guarantee that there is any associated economic value.

Second, given that validation of an activity is complete, it is next necessary to provide for the application of the activity to meet the needs of a user. For example, given that wheat acreage could be measured over a large area, dependably, reliably, accurately, these data must still be put into some useful context. To the farmer, this may mean biweekly estimates of wheat crop production yield and acreage. Thus, ERS data must be combined with other supporting data (it may very well be that the ERS data are the "supporting" data), processed into the information that the farmer needs and distributed to him on a timely basis. Because of the magnitude of this problem, improved wheat crop forecasts cannot come about overnight after the launch of an ERTS satellite. Appropriate government agencies must set up new operations to handle the new, better and greater volume of data. Often, this will involve inter-agency cooperation, for example, between USDA and NOAA.* It will also frequently involve a considerable expansion of computer and other data processing facilities.

It is important to remember that providing for information dissemination is an important component of the application process. The best information on wheat crop acreage and yield is of no value to the farmer after he has harvested and sold his crop -- or plowed it under.

The above two steps, validation and application, are sequential and come only after scientific and technical feasibility has been demonstrated. Clearly, these steps can require two-to-five years or more for various activities depending upon the scope, complexity and difficulties encountered. Yet, when they are complete, the benefit still does not emerge immediately, "off the shelf."

* To obtain this interagency cooperation there exists the Interagency Coordinating Committee Earth Resources Survey Program

The last step is transferral to the user. Again, this is a process that takes time. Assume that USDA is suddenly able for example, using an ERS system, to improve its annual wheat crop forecasts by, say, 2% (a reduction in expected error by 2% of the established expected error in any month). One could expect that farmers would take advantage of this improved information; but not immediately. First, the farmer must become aware that an improvement has indeed occurred and learn to make full use of the improved information. He has to gain confidence in the information.

In summation of the above qualitative analysis, it is apparent that anywhere from two to maybe ten years will pass before some major operational applications of ERS data are providing significant benefits. It is also apparent that this process is deterred somewhat by a present lack of a firm, long-term commitment to continuity of ERS satellite services, especially by a potential, imminent gap in service following the useful lifetime of the ERTS-B satellite.

4.2 The Value of Continuity of Service

Two distinct categories of Earth-resources activities are complemented with ERS information: mapping and monitoring. Mapping activities* include the use of ERS information in an open-loop decision process. ERS and other data are combined to provide timely information for a decision. Follow-up on the decision is then exclusive of the ERS system. A peculiar aspect of a mapping application from the user's point of view lies in the risk associated with the use of the ERS system. Many mapping applications are such as to permit the user to wait until the satellite has collected adequate data for his application before making any investment. His investment may, in fact, come as late as the time at which he actually has the ERS data in his hands. Furthermore, since there is no need to follow-up on his subsequent decisions using ERS data, he has now essentially eliminated all elements of risk associated with the data collection process. It remains only for him to process the data that he has in hand.

Figure 4.1 shows schematically the above process. Since the user does not begin his investment until after the satellite has completed (or nearly so) the required data collection,

* Not to be confused with map making.

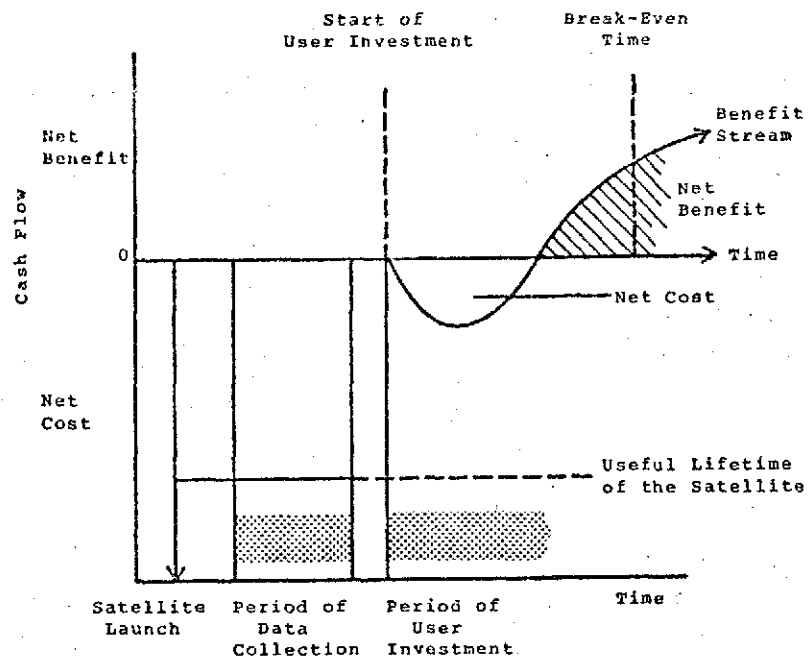


Figure 4.1 Scenario of User Involvement in an ERS Mapping Application

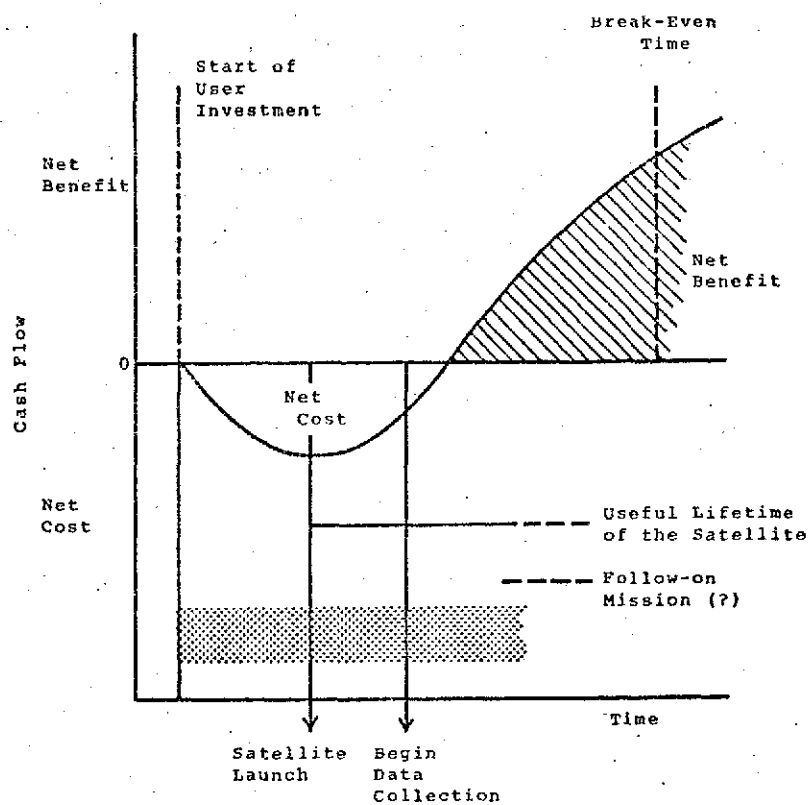


Figure 4.2 Scenario of User Involvement in a Monitoring Application

the time of satellite failure, interruptions in service, what comes next, etc., are all largely irrelevant to him. He has eliminated, by merely waiting for the appropriate time to invest, the risks associated with continuity of service.

Monitoring applications are substantially different from the above point of view. Monitoring decisions are made on the basis of data presented at a variety of points in time. The effects of previous decisions are evaluated using new satellite data in a closed-loop process and future decisions derive their bases from the effect of (monitored) previous decisions. Here, the investment must be made in *anticipation* of satellite data - often even before satellite launch - to insure an operational application capability early in the mission. Figure 4.2 details the monitoring application. It is now generally impossible for the user to protect himself against the uncertainties of the satellite launch and deployment, and the useful lifetime of the satellite. Furthermore, monitoring applications typically involve larger initial investments and have a longer time to break even. Thus the user often cannot help but to be concerned over potential interruptions in service and the nature of the follow-on program. Almost all large benefit ERS applications are monitoring applications.

Monitoring applications comprise two types of information gathering requirements:

- (1) *Complete area coverage requirement:* This requirement is typical of land use planning functions. The requirement in this case is to cover, with assurance, a total, contiguous area (a state, a drainage basin, an estuary). Under this requirement the incidence of cloud cover is an important and limiting factor in determining total system configuration (space, aircraft, ground). The economic issues arising from this requirement are addressed comprehensively in the land cover case study.
- (2) *Sampling of observations for national, regional or worldwide estimation requirements:* Requirements of this type are typical for purposes of national, regional or worldwide crop inventoring

and forecasting purposes, among others. In this application requirement all that is necessary is an assurance that enough statistically valid observations are made from each subregion, often "floating" sample observations, to allow a statistically significant regional, national or worldwide measurement, inventory or forecast. Under this requirement cloud cover poses no major problems to observations from space in the United States in the main application areas.

This assessment of the value of continuity of ERS service is based upon the above discussions. At the present time, most operational uses of ERTS data are for mapping applications. We would expect this to continue through the ERTS-B mission if no commitment for continuity of service occurs. However, if a commitment for continuity of service is obtained, then we would expect a gradual shift in emphasis toward monitoring applications. The value of a commitment to continuity of service is equal to the benefits foregone due to a gap.

The year-by-year present values of the projected benefit streams are shown in Figure 4.3. The projections are done separately for a 10 percent and a 15 percent discount rate, and include three separate cases: (1) with assumed continuity of service (i.e., no gap), (2) a one year gap in 1977, and (3) a two year gap in 1977-1978

Given continuity of service (Case 1) we assume in the calculations presented in Figure 4.3 that the benefits will grow by 1985 to at least \$350 million; this number is less than the lower limit of the annual potential measured benefits of Table 1.1a (\$430 million). We further assume conservatively, for the numbers shown in Figure 4.3, that the annual benefits from an ERS system will have reached at least \$600 million by 1992, i.e., the mid point of the total measured benefits of Table 1.1a (\$430 million to \$746 million). After 1992 we take the further conservative approximation that the benefits remain constant.

Given a gap in service, we would mostly expect benefits to accrue due to mapping applications until after the period of the gap. We assume here that the benefit stream curve merely shifts out in time by the duration of the gap. This assumption clearly understates the benefits foregone by the gap. Furthermore, the benefit streams presented are for the

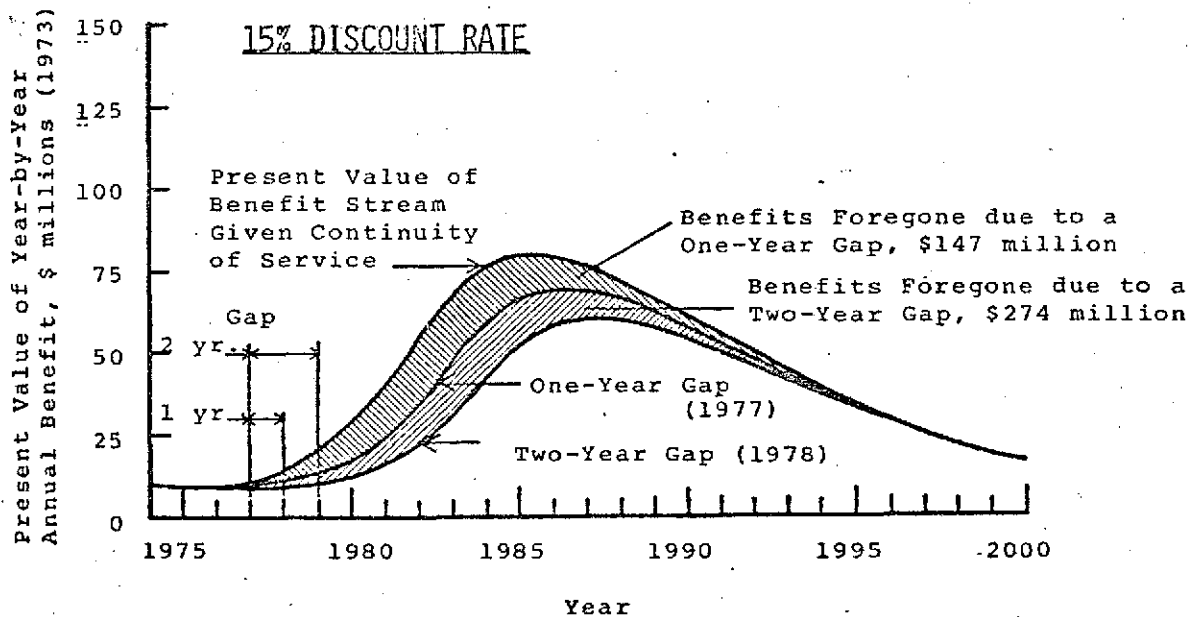
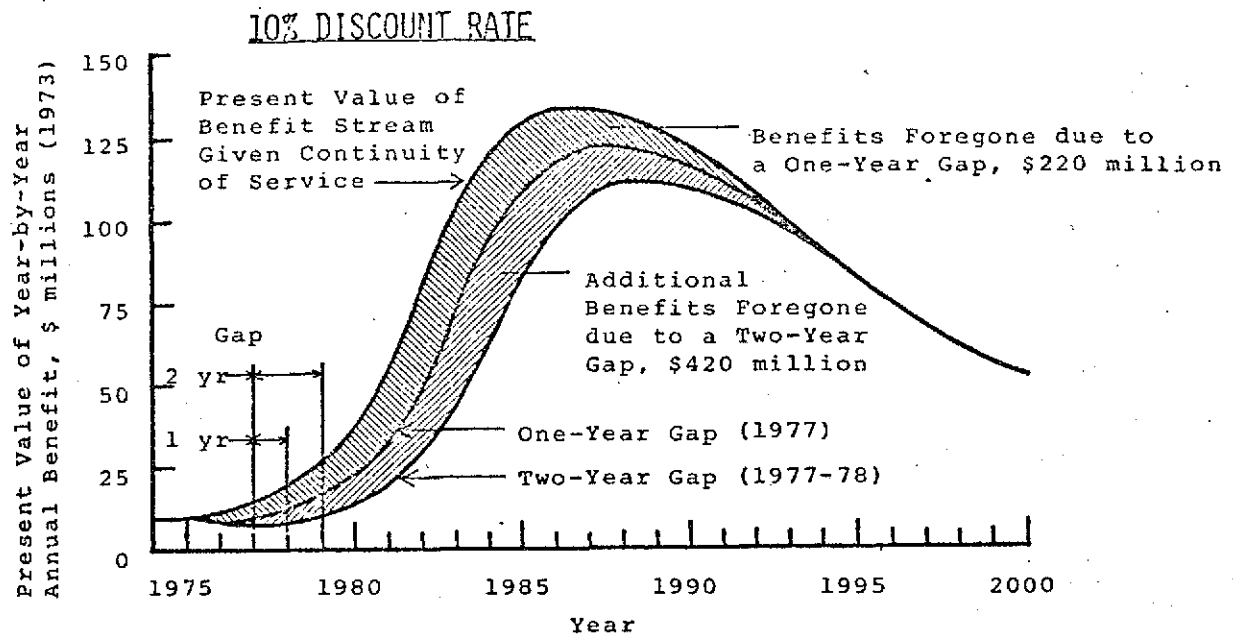


Figure 4.3 Benefits Foregone due to a One-Year and a Two-Year Gap Evaluated at 10% and 15% Discount Rates

firm, measured benefits only. The potential for added benefits makes the degree of conservatism used in this analysis even greater.

The benefits foregone in the event of a gap in ERS services are then obtained as the difference in present values of the benefit streams assuming continuity of service and assuming a one- or two-year gap in service. These are shown as the shaded areas in Figure 4.3. The present value of benefits foregone by a one-year gap occurring in 1977 are estimated at \$220 million (1973) at a 10% discount rate and \$147 million (1973) at a 15% discount rate. The present value of benefits foregone by a two-year gap occurring in 1977-1978 are estimated at \$420 and \$274 million (1973) respectively for a 10% and 15% discount rate.

5. INDIRECT BENEFITS

The "measured" ERS benefits discussed in the previous chapters are determined on the basis of in-depth economic analysis of specific resource management functions. Thus, these data are firm and fully defensible but, by their nature, can only represent a lower benefit bound. There exist many benefits that are not readily quantifiable or, for which there simply has not been sufficient time for examination in a fully defensible manner. Yet these non-measured benefits are extremely important to consider when trying to grasp the ultimate economic and societal significance of an ERS system.

Those benefits which are quantifiable but which have not been estimated by an in-depth economic analysis are included in the summary of benefits given in Table 1.1b and documented by RMF in Volumes III through X.

The remaining benefits fall into four categories and are discussed below. These are the benefits of research, intangible benefits, long-range versus short-range benefits and foreign aid benefits.

5.1 ERS Information as a Research Tool

It is all-too-evident that man's scientific understanding of his environment and the factors that influence it are presently insufficient to provide an adequate life for all people. At this moment, millions of people are threatened by starvation, significant climatic changes appear to be occurring, pollution adversely impacts the quality of life in industrialized nations and certain natural resources are fast disappearing. Even partial solutions to any of these problems clearly have very large associated economic benefits. But real solutions can result only from a better scientific understanding of the earth and its worldwide resources. ERS information provides one tool for advancing science and technology in this direction.

Attempting to measure the benefits of an ERS system as a research tool, however, is fraught with uncertainties. What will be the success of the research? When will it occur? What will be its operational impact? Obviously, these questions cannot be answered with any degree of certainty in advance. In fact, generally, it is not even possible to predict the specific research wherein advancements will be made. Nonetheless, there are a few specific areas wherein the applications of ERS information to research appears clear and where some estimate of the benefits is possible. One such area is atmospheric pollution. (RMF No. 6.2.2, documented in Volume VIII).

There currently exists a great deal of uncertainty both regarding the economic costs of atmospheric pollution and the cost of preventing this pollution. Ideally, the Environmental Protection Agency would control pollution to minimize its total cost to society. Because of present uncertainties, however, such control sometimes is a hit-or-miss affair. If ERS information can effect only a one-to-five percent reduction in the uncertainty of the cost of pollution, the aggregate value to the people of the United States is estimated conservatively to be from \$5 to \$27 million annually. This is not due to monitoring pollution but only due to a better understanding of its costs and could very well derive from only one or a few ERS satellite images (for example, Figure 1.3).

Extrapolating these results to the myriad of possible research topics that will be impacted by ERS information, it is not difficult to assume that the total benefits of an ERS from research alone may exceed \$100 million annually. However, *no credible estimates of such a benefit are now, or perhaps ever will be, possible.*

Finally, an example of a truly unexpected and unpredictable application of ERTS-1 images--archaeology.* In ERTS images, vegetation variations can be traced that mark the wandering courses of ancient river beds. In 1975 a test will be made over a specific area in England to see if ERTS-1 and ERTS-B images can be used to pinpoint the period in the growing season when photographs from a plane can best pick up ancient man's traces in the fields. These techniques may be extended one day to disclose long linear features, ancient roads or canals. One such feature was disclosed in an ERTS-1 image over Greece: The Corinthian Canal.

* Rainey, Froelich, "Technology is Forcing History to Change," The New York Times, August 25, 1974. Froelich Rainey is director of the University Museum in Philadelphia.

5.2 Intangible Benefits

By monitoring remote and undeveloped areas of the earth, it is possible to better determine man's impact upon many diverse areas. Proper control of this impact can limit permanent damage in a way that man sees fit. For example, this century has already seen the extinction of many wildlife species. ERS information provides one tool, often a very effective one, for saving wildlife habitats from destruction and thus preserving certain species for future generations (e.g., estuarine area inventorying and monitoring; 80+% of all salt water fish spawn in estuaries).

ERTS-1 and Skylab images were recently used in a legal battle to protect an endangered watershed area in central Florida. The result of this effort is that developers in this area will "shape their developments to the land instead of shaping the land to the developments."* It has also resulted in lower population densities and prohibited the connection of drainage systems with the Withlacoochee River. Mangrove areas are important sources of food for animal and fish life.

What is the economic value of preserving wildlife habitats and breeding grounds and, thus, the species themselves? This cannot be measured to the satisfaction of even a small cross-sample of economists, but its value to future generations of man is real.

5.3 Long-Range versus Short-Range Benefits

In order to be credible, the hard benefit estimates presented are based on the demand for data, the price structures and resource availabilities of today and are limited to those applications of ERS data which are now obvious and quantifiable. These can be referred to as short-range benefit estimates. Clearly, all these parameters will change and it is almost certain that they will change so as to increase the benefits actually obtained from an ERS system even in constant dollars. Again, however, no credible estimate of this long term application outlook was attempted.

* "Space Data Help in Swamp Dispute", The New York Times, August 10, 1974.

5.4 ERS Information as Part of a Foreign Aid Program

ERTS-1 imagery has already been internationalized by being provided to all countries that submitted suitable proposals and were willing to report periodically on findings. As a result, an upwelling in interest and support of the ERTS Program by foreign countries is now in evidence. One of the more dramatic examples of foreign results to date is shown in the ERTS frame that helps to explain the causes of the devastation of the Sahel (see Figure 1.5). It is now known that drought is but one of the causes of the famine in that area.

Particular regard has been expressed by developing countries which stand to realize, relative to their information needs, large benefits. In any event, the program represents very low cost foreign aid which may be highly valued by the recipient country.

The Agency for International Development has sampled ERTS-1 benefits in four developing countries: Bolivia, Botswana, Kenya, and Thailand.

In Bolivia, a complete natural resource inventory has been made from one ERTS frame by the creation of ten thematic maps. Also, there has been some demonstration of the economic utility (however, not yet quantified) of the imagery for geological explorations and the location of pipelines and other infrastructure investments. There is some evidence that the imagery will help to more efficiently utilize land on the Altiplano, which has been the traditional center of Bolivian population.

In Thailand, the imagery is being used for many economic activities which include rice crop forecasting, geological exploration, water resource management, and land use planning. The rice crop forecasting benefits may be significant since the imagery will provide accurate and earlier estimates.

In Kenya, an important problem is the management of grazing lands. These must support Kenya's commercial cattle industry, provide the required habitat for its wild animals, and give the Masai, who raise noncommercial cattle, sufficient biomass to support their nomadic cattle-based culture. The wild animals provide the basis for Kenya's tourism industry, its most important source of foreign exchange. The information that can be extracted from ERTS images is expected to

provide much greater understanding of the ecological processes that determine much of the country's potential.

In Botswana, a country which is now at an early level of economic development, information from ERTS is being used for geological exploration, water research, and cartographic mapping. In a few instances ERTS images are being directly used for aerial navigation in remote areas! Botswana is also interested in developing a tourism industry based on its wildlife, and the imagery could be used for its optimal location and management from the standpoint of the economy and the preservation of Botswana's environment.

6. EARTH RESOURCES SURVEY IN A SYSTEMS CONTEXT

For the purpose of estimating the benefits presented in this overview, it has been necessary to make several assumptions regarding the context in which the space system will function. These include certain technical capabilities of the ERS satellites plus the capabilities of other coexisting satellite systems, particularly weather satellites, and of medium-to-high altitude aircraft. For the most part, it is assumed that aircraft possess the technical capability to perform all the functions of an ERS satellite. One might not believe this to be the case and, indeed, there are certain technical limitations inherent to aircraft (for example, navigation accuracy) but, in the large, the limitations of an all-aircraft ERS system are *economic* ones.

Benefits to the United States from remote sensing of United States territory only support a level of activity that is approximately six to twelve times full coverage of the contiguous 48 states per year. The Land Cover Study summarized in Chapter 3 concludes that this activity is most cost-effectively accomplished with a composite satellite-aircraft system that includes either two or three ERS satellites. The results presented assume that this approximate land cover capability will be obtained and, in fact, indicate that additional benefits can be obtained from even higher activity levels, for example, 12 times full United States coverage yearly.

In the absence of any cloud cover, even the higher activity level could be supported by a single satellite. The presence of clouds, however, creates a requirement for a backup to a single satellite. The backup can be in the form of additional satellites and/or aircraft. The marginal cost of data collection by satellite is only a small fraction of the marginal cost of data collection by aircraft. However, aircraft can be directed to cloudfree areas so that a higher percentage of their imaging is useful. Thus, the trade-off is between non-directable imaging, such as ERTS and directable imaging, such as aircraft and higher altitude satellite systems. This study assumes that demanded coverage is met using the most cost-effective hybrid satellite-aircraft system but excluding pointable satellite imaging. It is quite possible that an all-satellite system, using satellites at

different altitudes, for example, low altitude and synchronous altitude, and using satellites of differing capabilities, for example, with active sensors, is better than the system considered. Nonetheless, the role of satellites over aircraft in remote sensing is firmly established.

This study also assumes that all ERS data collected are available on a nondiscriminatory and timely basis to all users. Thus, the benefits obtained are, in fact, benefits to society on the whole and not "zero sum" exchanges (I win, you win, not I win, you loose). However, to affect timely distribution of ERS data and, more appropriately, information, the data processing systems currently in use will have to be replaced with a data processing system capable of processing the plethora of ERS data in real or near-real time (throughput rate equals input rate). While this will require a substantial investment, such data processing rates are, nonetheless, demonstrated state-of-the-art. Present, special purpose, computer systems* are capable of processing ERS data inputs from three satellites in one computer, in real time. Further work is necessary to define the data processing requirements and, from that, the associated costs. However, it is quite clear that, over any reasonable range of data processing requirements, the benefits to be obtained from agricultural applications alone more than support the investment.

Some further changes in the satellite system may also be desirable from an economic viewpoint. For example, present ERTS coverage of nearly the entire land mass of the world** will require about 14 active ground stations at a cost of \$3.06 million to \$5.44 million each*** (without extensive automatic data processing capability). Aside from the politics of user nation involvement and the benefits of the sale of ERS ground stations and data processing equipment to foreign nations, a more cost-effective approach to data collection would appear to be data relay satellites. Data relay satellites could allow ERS data processing to be completed in real

* High Speed Digital Data Processing and Laser Display Equipment, CPF-1-72-038-1, General Dynamics/Electronics Division, San Diego, California, 20 February 1973.

** See Chapter 1, Source Document, Vol. II.

*** Beilock, Milton, M., Systems for Acquisition, Processing, and Dissemination of Earth Resources Satellite Data, December 1973, p. 1-6.

time in a single, appropriately located facility and would obviate the need for expensive data transmission to the United States from foreign users. Foreign users who wish to maintain their own ground stations and data processing facilities could still do this. Furthermore, data gathering could then be truly worldwide, including also ocean areas.

Much confusion exists over the proper resolution for ERS satellite sensors. The resolution of the ERTS satellites is not limited by technology to its present levels. The benefits of remote sensing increase as the technical attributes of the system improve. In most application cases this means more resolution than now provided by ERTS. The economically optimum resolution occurs when the incremental cost of improving the resolution equals the incremental benefit obtained from the increase in each application area. At what point this occurs can only be left for speculation at this time. However, the present state-of-the-art of data processing is such that 10 meter resolution image data could be processed in real time and straight forward projections of this technology indicate that soon 3 meter image data could probably be processed in real time. This range of technology probably includes the economically optimum resolution required in most civilian applications.

Simultaneously, improvements in spectral resolution should increase the potential ERS benefits substantially.

Despite the several obvious and significant improvements that could be obtained in an ERS system, THIS REPORT BASES ITS CONCLUSIONS ON THE CONSERVATIVE VIEWPOINT THAT THE MEASURABLE BENEFITS ARE DUE ONLY TO ACTIVITIES REQUIRING TECHNICAL CAPABILITIES PRESENTLY DEMONSTRATED BY ERTS AND NOT PERFORMED BY OTHER EXISTING CIVILIAN SATELLITE SYSTEMS. These results alone provide economic justification for an ERS system with capabilities similar to ERTS, or better if the cost is not too high. The fact that system alternatives are available merely serves to reinforce this conclusion. Furthermore, while the conclusions presented herein are based on the measurable benefits only, it is very short-sighted to neglect the potential benefits to mankind of ERS activities from space. The order of magnitude of these benefits is indicated by the benefit numbers presented in Table 1.1b. The long term potential benefits could only be guessed at.